NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

LOGISTICS AND MAINTENANCE CONCEPTS FOR A FUTURE NAVAL FORCE

by

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December 2001

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Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
19 Dec 2001	N/A	-

Title and Subtitle	Contract Number
Logistics and Maintenance Concepts for a Future Naval Force	
	Grant Number
	Program Element Number

Author(s)	Project Number
Brown, Kenneth J., Ray, Joe, Edge, William, Raia, Gerald	
	Task Number
	Work Unit Number

Performing Organization Name(s) and Address(es)	Performing Organization Report Number
Naval Postgraduate School Monterey, California	

Sponsoring/Monitoring Agency Name(s) and Address(es)	Sponsor/Monitor's Acronym(s)
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes

Abstract

Subject Terms

Report Classification	Classification of this page
unclassified	unclassified

Classification of Abstract	Limitation of Abstract
unclassified	UU

Number of Pages
194

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REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December, 2001	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Logistics and Maintenance Concepts for a Future Naval Force			**5. FUNDING NUMBERS**
6. AUTHOR(S) Ray, Joe F.; Edge, William W.; Raia, Gerald P.; Brown, Jr. Kenneth J.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/ MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT *(maximum 200 words)*
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14. SUBJECT TERMS Logistics, CROSSBOW, Maintenance, Life Cycle Cost, Simulation, Culture			**15. NUMBER OF PAGES**
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

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LOGISTICS AND MAINTENANCE CONCEPTS FOR THE FUTURE NAVAL FORCE

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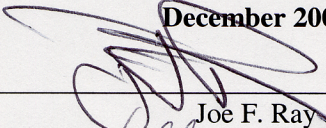Submitted in partial fulfillment of the
requirements for the degree of

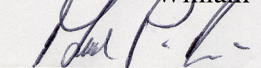**MASTER OF SCIENCE IN MANAGEMENT**
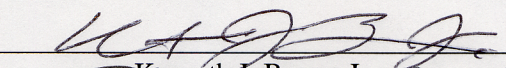
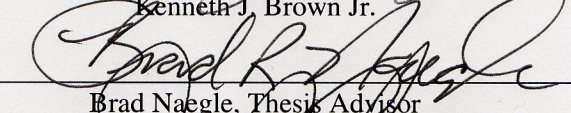from the

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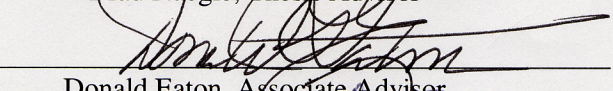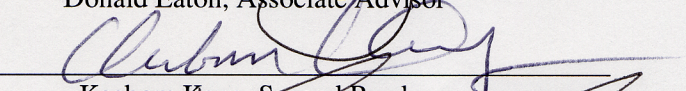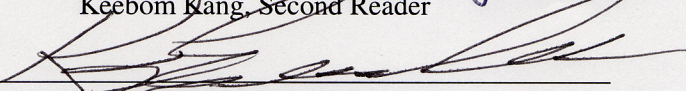
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ABSTRACT

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LIST OF ACRONYMS

3M	Maintenance Material Management
A_o	Operational Availability
AAAV	Advanced Amphibious Assault Vehicle
AC	Aircraft
ACWT	Average Customer Wait Time
ADT	Administrative Delay Time
ADV	Advance
AIMD	Aviation Intermediate Maintenance Depot
AIT	Automatic Identification Technology
ALRS	Auto Launch and Recovery System
AOE	Fast Combat Support Ship
APU	Auxiliary Power Unit
ATAC	Advanced Traceability and Control System
ATMSR	Aviation Type Model Series Report
AV	Air Vehicle
AVCAL	Aviation Consolidated Allowance List
AVDLR	Aviation Depot Level Repairable
BTWEUAV	Basic Training Weeks Enlisted UAV
BUPERS	Bureau of Personnel
C4I	Command, Control, Communication, Computers and Intelligence
CAD	Charged A Device

CAIG	Cost Analysis Improvement Group
CASREP	Casualty Report
CASS	Consolidated Automated Support System
CBM	Condition Based Maintenance
CHINFO	Chief of Information
CINC	Commander in Chief
CIWS	Close In Weapon System
CM	Configuration Management
CNAV	Computer, Navigation
CND	Can Not Duplicate
CO	Commanding Officer
COMNAVAIRLANT	Commander Naval Forces Atlantic
COSAL	Consolidated Ship Allowance List
CPO	Chief Petty Officer
CV	Aircraft Carrier, Conventional, ship designator
D-Level	Depot Level
DARPA	Defense Advanced Research Projects Agency
DD-X	Destroyer, prototype
DLA	Defense Logistics Agency
DLR	Depot Level Repairable
DOD	Department of Defense
DON	Department of the Navy
DOP	Designated Overhaul Point

DSP	Designated Storage Point
DSS	Decision Support System
E	Enlisted
ECP	Engineering Change Proposal
EDI	Electronic Data Interchange
EPMAC	Enlisted Placement Management Center
EXPO	Exponential Distribution
F-14	Fighter aircraft designator (Tomcat)
F/A-18	Fighter/Attack aircraft designator (Hornet)
FISC	Fleet Industrial Supply Center
FLE	Fleet Life Expectancy
FMC	Full Mission Capable
FOTE	Follow-On Test and Evaluation
fpt	Preventive Maintenance Rate
FRS	Fleet Replacement Squadron
FY	Fiscal Year
G stores	Temporary Storage
GAO	Government Accounting Office
GCE	Ground Control Equipment
HQ	Head Quarters
H-60	Helicopter designator (Seahawk)
ICP	Inventory Control Point
IDTC	Inter Deployment Training Cycle

IFF	Interrogation, Friend or Foe
I-level	Intermediate Level
ILS	Integrated Logistic Support
IMA	Intermediate Maintenance Activity
INSTR	Instructor
IOC	Initial Operational Capability
JASS	Job Advertisement and Selection System
JM-TADIL	Joint Multi-Tactical Digital Information Link
JROC	Joint Requirements Oversight Council
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LDT	Logistics Delay Time
LT	Light Tons
M	Mean Active Maintenance Time
M&S	Modeling and Simulation
M/A	Maintenance Action
MA	Maintenance Action
MDT	Maintenance Down Time
MFHBMA	Mean Flight Hours Before Maintenance Action
MFHBF	Mean Flight Hours Before Failure
MFHBR	Mean Flight Hours Before Removal
MFHBF	Mean Flight Hours Before Failure

MNS	Mission Needs Statement
MOOTW	Military Operations Other Than War
MTBF	Mean Time Between Failures
MTBM	Mean Time Between Maintenance
$MTBM_c$	Mean Time Between Maintenance (corrective)
$MTBM_p$	Mean Time Between Maintenance (preventative)
MTTR	Mean Time To Repair
NALDA	Naval Aviation Logistic Data Analysis
NADEP	Naval Aviation Depot
NASNI	Naval Air Station, North Island
NAVAIR	Naval Air Systems Command
NAVICP	Navy Inventory Control Point
NAVSEA	Naval Sea Systems Command
NAVSUP	Naval Supply Systems Command
NAVTRANS	Naval Transportation Support Center
NCO	Non Commissioned Officer
NETPDTC	Naval Education & Training Professional Development & Technology Center
NMC	Not Mission Capable
NORM	Normal Distribution
NORMINV	Inverse of the Normal Cumulative Distribution
NORVA	Norfolk, VA
NPS	Naval Postgraduate School
NPV	Net Present Value

NRFI	Not Ready For Issue
O-level	Organizational Level
O&M	Operations and Maintenance
O&S	Order and Shipping
OEM	Original Equipment Manufacturer
OPS	Operations
P-3	Patrol aircraft designator (Orion)
PHM	Prognostic Health Monitoring System
PM	Program Manager
PMC	Partial Mission Capable
POL	Petroleum, Oil, Lubricants
PV	Present Value
QOL	Quality of Life
R_{sys}	System Reliability
$R_{component}$	Component Reliability
RCM	Reliability Centered Maintenance
RDT&E	Research Development Test and Evaluation
RETOK	Retest O.K.
RF	Radio Frequency
RFI	Ready For Issue
RMVLS	Removals
RNAV	Radar Navigation
RNAVWCS	Area Navigation and Weapons Control System

RTAT	Repair Turn Around Time
SDE	Single Definition Engineering
SH-60	Anti-Submarine Helicopter designator (Seahawk)
SHP	Shaft Horsepower
SITREPS	Situational Reports
SLAP	Service Life Adjustment Programs
SLEP	Service Life Extension Programs
SMA	Supply Material Availability
SNT	Serial Number Tracking
SQ/SQDN	Squadron
SRT	Supply Response Time
TAT	Turn Around Time
TAV	Total Asset Visibility
T/M/S (TMS)	Type/Model/Series
TRANSCOM	Transportation Command
TRIA	Triangular Distribution
TOC	Total Ownership Cost
UCAV	Unmanned Combat Aerial Vehicle
UCAV-N	Unmanned Combat Arial Vehicle-Navy
VF	Fixed Wing Fighter Aircraft squadron designator
VAMOSC	Visibility and Management of Operating and Support Costs
WIP	Work In Process
WRA	Weapons Replaceable Assembly

WUC   Work Unit Code

WWD   Widespread Wire Damage

ACKNOWLEDGEMENTS

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I. INTRODUCTION

A. OVERVIEW

The projected threat environment in the year 2020 generates the need for a weapon system that has an enhanced capability in littoral scenarios as well as supporting major operations other than war (MOOTW) [Farrer, 2000]. The over arching objective of the CROSSBOW project is an attempt to assess the potential threat scenarios in the year 2020 (e.g., resultant proliferating weapon technologies, dynamic socio-economic conditions) and to propose the design for a weapon system that will ensure U.S. naval superiority is maintained.

These scenarios dictate the need for a widely distributed, interconnected force for reduced attritional risk and increased tactical connectivity. These scenarios also demand weapons that are fast, stealthy, force multipliers in power projection, complementary to the capabilities of Carrier Battle Groups, and jointly interoperable with various forces, domestic and international [Shelton, 2001]. Designed to operate primarily in littoral waters, these weapon systems will be required to operate independently in minor contingencies, in areas inaccessible to deep draft combatants.

The CROSSBOW project examines these provisions within a conceptual weapon system. The notional CROSSBOW force consists of eight surface combatant/aviation vessels (SEA ARCHER), twenty anti-ship/air escort vessels (SEA LANCE) and two logistics support vessels (SEA QUIVER). Each SEA ARCHER will carry a complementing unmanned combat air vehicle (UCAV) squadron of eight SEA ARROWS. These weapon systems will be specifically designed to work in concert with each other – creating synergy in their joint employment during a mission.

The weapon systems are to leverage weapons technology projected to mature by 2012 in order to realize an initial operational capability (IOC) of 2020. The SEA LANCE design is the study of a previous Naval Postgraduate School Total Ship Systems Engineering effort and will not be discussed in this analysis [Naval Postgraduate School, 2001]. The CROSSBOW study, as a whole, takes the SEA LANCE study further by

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incorporating and integrating the SEA LANCE notional design characteristics and operational capabilities into the SEA ARCHER and SEA ARROW design characteristics. The specific design criteria of the SEA ARCHER and SEA ARROW are discussed in the Mission Need Statements (Appendices A and B). The SEA QUIVER is a notional design and is discussed only in broad terms in Appendix A.

Naval Expeditionary Logistics [Committee on Naval Expeditionary Logistics, 1999a] further validates the need to study threat scenarios within the framework provided by the CROSSBOW project. Navy tacticians have realized that future conflicts will involve small, semi self-sufficient combat units and ships that are expected to either resolve or contain a conflict until the arrival of reinforcements or a joint military operation is commenced. These combat units must maintain battle readiness despite reduced manning, potential losses of forward supply points, and extended material pipelines.

The often-neglected area of *logistics* and *maintenance*, cumulatively termed sustainment for this analysis, must evolve to accommodate these new and expanding circumstances. Traditional approaches to sustainment will be ill fitted to the rapidly paced, highly focused requirements of future combat units. During Operations Desert Storm and Desert Shield, theater commanders and logistics officers were routinely frustrated with the inability to quickly locate needed stock, track the status of requests, or track shipments within the theater [National Research Council, 1999]. Emphasis must be placed upon developing a robust maintenance system that is facilitated by an efficient logistics system - driven by a responsive information system, an intelligent transportation network, and a comprehensive data analysis capability.

This thesis will explore these sustainment requirements within the context of the CROSSBOW weapon system. The goal is to assess current misaligned sustainment processes – thus exposing areas for improvement translating into increased operational readiness. The intended endgame of this analysis is the emphasis of making sustainment a fore thought, rather than an after thought, in the design of any weapon system.

B.   OBJECTIVE - STATEMENT OF TASKS

This analysis will examine the potential of new technologies and concepts that reduce the size of the onboard sustainment structure while enhancing readiness of the CROSSBOW weapon system.   It will describe and recommend areas of research, methodologies, and technological development the Navy should invest in *now* to field systems that will enhance logistics and maintenance capabilities for a battle force in 2020.   In the undertaking of this thesis, this analysis group will perform the following tasks:

- Review the current Navy sustainment methodology and assess some of the prevalent problems experienced by Logisticians and Maintenance Officers (Chapter II).

- Identify and evaluate areas of research, methodologies, and concepts that will reduce the need for current support infrastructures while increasing the operational readiness of a weapon system (Chapter II).

- Develop a framework, integrating the selected research and methodologies, that will define the support and sustainment system for CROSSBOW (Chapter II).

- Perform a Life Cycle Cost Analysis (LCCA) to assess the total ownership cost of the SEA ARROW and SEA QUIVER.   From this analysis, determine the cost drivers of the SEA ARROW and SEA QUIVER and discuss how efficiencies could be achieved through the CROSSBOW framework. (Chapter III).

- Test the validity of the CROSSBOW framework using Arena$^{©}$, a computer modeling and simulation tool.   The analysis will compare models of current sustainment methodologies against models with incrementally increased logistics efficiencies (Chapter IV).

- Discuss the potential benefits, of the framework, in relation to managing the current Aging Weapon Systems dilemma (Chapter V).

- Discuss the need for transformation within Navy culture that currently hinders sustainment in the alignment of objectives with available resources (Chapter VI).

- Develop a roadmap (Appendix C) that will list:

  - the specific technologies, research, and methodologies found suitable in meeting the objectives

- the industry and government leaders that are currently developing and advancing the technology

- contact information to facilitate further study

The reader should note the Roadmap (Appendix C) is not all inclusive of the technologies, research, and methodologies available, but serves as a starting point for further research.

C. SCOPE

Due to the *conceptual* nature of this study, an in-depth analysis of the elements involved in determining an exact sustainment support structure will not be accomplished. What is intended is a study to provide some insight into innovative maintenance and sustainment concepts that will enhance overall supportability of not just the CROSSBOW weapon system, but any weapon system.

D. METHODOLOGY

Department of Defense Instruction 5000.2 [Defense Acquisition Deskbook, 2001] establishes the methodology for ascertaining specific requirements from a mission need statement. This methodology, referred to as the Requirements Generation System, is iterative in nature – producing information for decision-makers on specific requirements as defined within the mission needs statement. The user typically defines mission needs in broad operational terms and then evolves the needs into specific operational requirements. A Joint Requirements Oversight Council (JROC), or other appropriate requirements authority, validates and approves the mission needs - ascertaining that a non-material solution alone cannot satisfy the identified needs and recognizes that a potential new concept or system material solution should be considered. These requirements are then assessed, normally through a systems architecture/engineering methodology, to produce a system or concept that fulfills the mission needs statement.

In light of the iterative and comprehensively time-consuming nature inherent within the established Requirements Generation System, this standard DOD methodology is not feasible within the scope of this analysis. Recognizing this constraint, the following alternate methodology will be used which consist of the following modified steps:

- Establish **Precepts** to regulate the guidelines and scope for the analysis to be performed within. These **Precepts** establish that:

    - All research, methodologies, and concepts must fully support the requirements established within the Mission Need Statements

    - All research, methodologies, and concepts will enhance U.S. National Security Strategy and produce a tactical advantage through efficiency and speed for weapons systems repair and supportability

    - All research, methodologies, and concepts must create sustainment enablers which ensure:

        - Accurate assessment of weapon system's operability and repair component requirements upon system degradation
        - Speed in determining degree of weapon system operability, in determining repair component requirements, in determining best delivery avenues for repair components, and in repair of the weapon system
        - Effectiveness in supporting and maintaining weapon system operability despite a dynamic battle space environment
        - An acceptable level of system risk when compared to capability, operability, and human factors designed into the system

    - All research, methodologies, and concepts should conform to Joint Multi-Tactical Digital Information Link (JM-TADIL) standards [Joint Multi-Tactical Digital Information Link, n.d.]. Conformance to JM-TADIL standards will create a system that is universally compatible, flexible, dynamic, and an integrative system for all levels of:

        - Existing legacy logistics and maintenance systems
        - New logistics/maintenance systems
        - Existing tactical data links

    - All research, methodologies, and concepts must be as autonomous as possible, leveraging technology to support:

        - Reduced manning
        - Speed
        - Efficiency
        - Security

    - All research, methodologies, and concepts must support peace and wartime operations assuming limited to no forward basing [Committee on Naval Expeditionary Logistics, 1999b]

- Conduct a literature review of periodicals, theses, magazine articles, World Wide Web searches, and other library information for innovative techniques and ideas

- Visit and conduct interviews with leading industry and government leaders to ascertain cutting edge techniques and methodologies in sustainment

- Within the guidelines of the **Precepts**, identify sustainment technologies, methodologies, and concepts that fulfill the requirements established within the Mission Need Statements

- Create a support and sustainment framework that integrates the technologies, methodologies, and concepts into a cohesive design

- Develop a Life Cycle Cost Analysis (LCCA) for the SEA ARROW and SEA QUIVER platforms. From this analysis, ascertain potential areas of cost efficiencies that could result from CROSSBOW technologies and methodologies.

- Using the Arena$^©$ simulation software, simulate the existing logistics and maintenance methodologies as well as the proposed CROSSBOW methodology. Compare and analyze the data produced from the simulations

- Consolidating all literature review data, interview data, LCCA, and simulation data, propose recommendations on findings. Compose a roadmap of the selected technologies, techniques, and methodologies for reference and further study

- Discuss the potential benefits of the proposed CROSSBOW sustainment concepts with respect to the current *aging weapon system* issue

- Discuss how Navy culture impairs attempts at improving the existing logistics and maintenance system, how the implementation of CROSSBOW sustainment concepts would be hampered by this culture – and the need for change

- Summary of Analysis

II. BACKGROUND

A. THE CURRENT SUSTAINMENT ENVIRONMENT

Each weapon system in the Navy is supported through the Naval Supply System by means of replaceable or repairable components. Depots Level Repairables (DLR) are the components, or subassemblies, that can be replaced to make an unserviceable end item function properly. DLRs are usually high cost items with relatively long procurement lead times. These components are managed by Naval Supply Systems Command (NAVSUP) requiring intensive resources, manpower, and intellectual capital for determining proper levels of inventory, positioning of components, component repair requirements at repair depots, and efficient delivery systems to fleet activities.

Coinciding with the supply system, the Navy employs three levels of maintenance for direct support to operational units: Organizational level repair (O-level; trouble shooting, removal and replacement of components on major equipment, preventive maintenance actions), Intermediate level repair (I-level; low volume, low-technical economic repair of components), and Depot level repair (D-level; high volume, high technical repair of components at established Naval repair facilities or the original equipment manufacturer [OEM]). This methodology is established under the premise of *lowest possible economical repair* to regain serviceability of the weapon system.

Naval surface and submarine combatant forces utilize a distinct, though similar, multi-tiered repair system that allows for optimized use of commercial and military support structures. This thesis will discuss sustainment from an aviation viewpoint. But the concepts presented are applicable to all communities.

Figure 1 outlines a simplified flow of an Aviation Not Ready For Issue (NRFI) failed component from the organizational level unit (O-level) sent to repair facilities (I-level/D-level) and an Aviation Ready For Issue (RFI) repaired component, in turn, sent to requesting commands or intermediate storage. Functions within the flowchart requiring the expenditure of significant manpower to accomplish have been highlighted and clearly indicate the manpower intensive requirements of the current system. These flow points,

with "a man in the loop," illustrate time delays in the repair process until the performance of some action is completed.
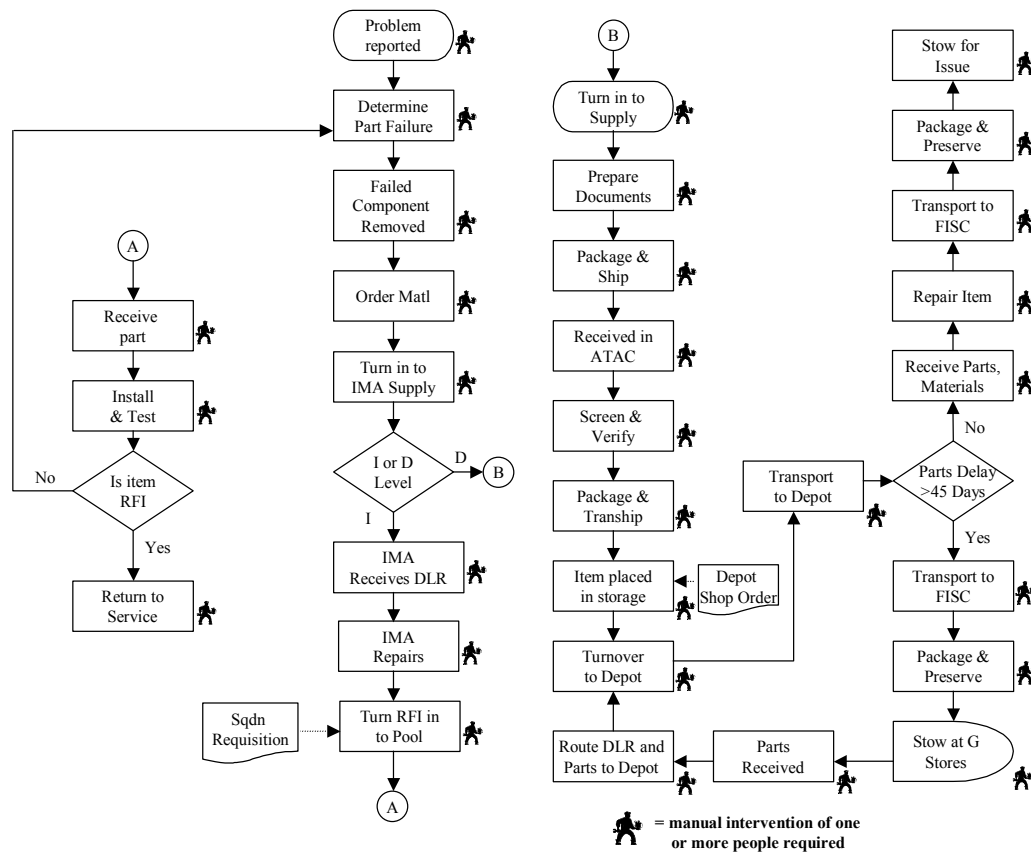
Figure 1.   Typical Carcass Flow NRFI to RFI.

Prohibitively, customers lack visibility of NRFI components repair status once inducted for repair. Nor do customers have visibility of RFI components located within an intermediate storage location − thus precipitating the need for *expediters* who track NRFI and RFI component status for repair time frames, shipping status, or RFI component availability at the intermediate storage location. This example is representative of the difficulties faced by the fleet customer.

Other prevalent issues have been identified that show current naval supply support inefficiencies to include:

- The Navy, and industrial stakeholders, maintain a legion of individualized databases utilized to manage and track components in all phases of supply

and maintenance systems. Figure 2 provides the current database environment distributed throughout the Navy. These disparate computer systems are disconnected and largely un-linkable for data sharing, archaic in design, manpower intensive, costly, and inflexible in data reporting capability.
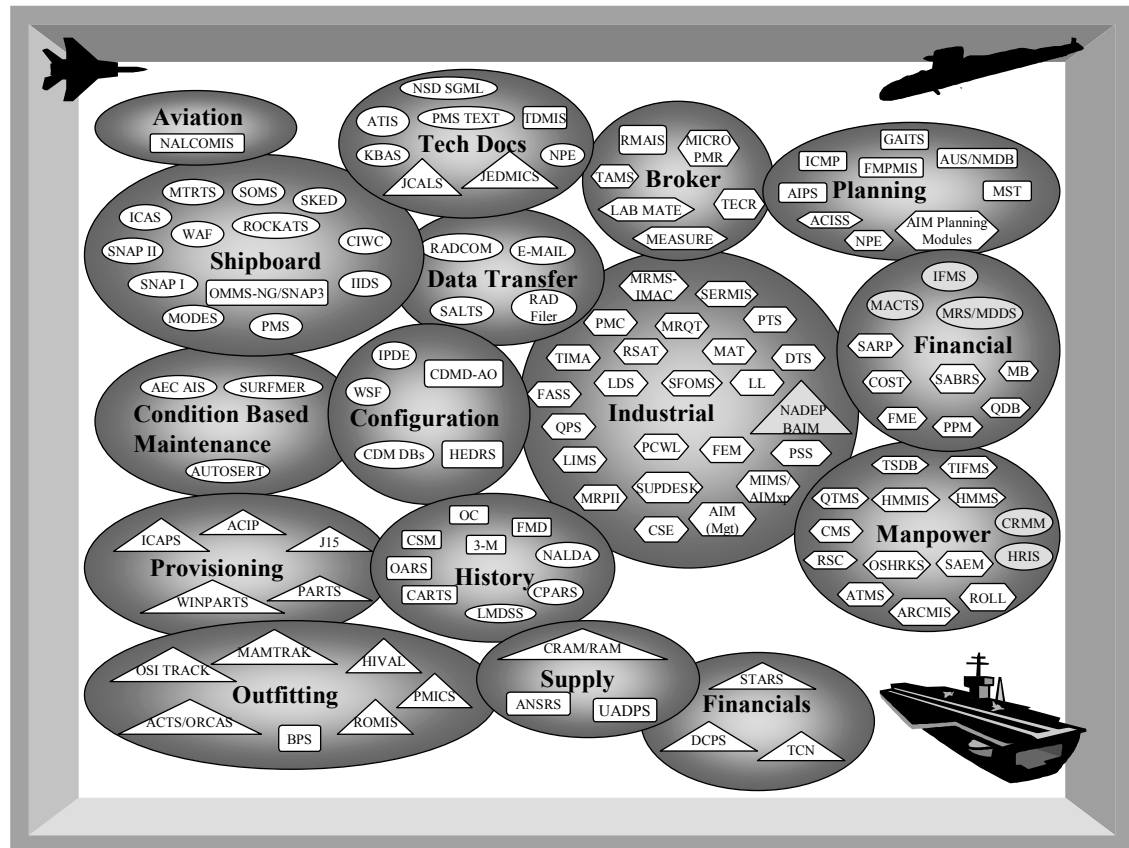
Figure 2. Today's Fleet Support/CM Data Environment.
(From: Courtesy of DD-X Program Office)

- The Department of Defense transportation system provides little to no repairable component visibility during shipping and transit. The established system is a loosely interconnected *construct* made up of multiple military services and commercial transport capabilities. The systems operate mutually exclusive of each other, are not compatibly designed, and share information sparingly. This lack of information results in losses, delays, inaccurate forecasting, and inventory control/accounting disparities.

- The Advanced Traceability and Control System (ATAC) is the Navy's logistics pipeline that integrates the management and transportation of weapon system components, or depot level repairables (DLRs), into a single physical distribution and control system. The essential premise of this system is a *one for one* exchange of a broken component for a serviceable component. If a serviceable component is issued without the return of a subsequent and matching broken component, the logistician incurs a penalty cost. Lacking the ability to track the broken component during transit to the repair facility, the logistician is unable to determine when, or where, the component was lost. Severe costs are often imposed upon the logistician and the command - without a means for determining an asset's disposition and accountability during transit.

The <u>maintenance repair process</u> is just as complex and fraught with its own inherent problems. Components are becoming more complex and require more skill to troubleshoot and repair. Test equipment is becoming commensurately complex and multi-functional in application. Maintenance managers must face this growing complexity with additional issues to include:

- The Navy's method for assigning technicians to billets is not comprehensive enough to ascertain their current *experience* levels - as technicians lose or gain experience throughout their careers. Combine this shortcoming with the Navy's tendency to move technicians between a variety of platforms (e.g., F/A-18, F-14, H-60), and there is no manner of establishing a technician's current technical ability from weapon system to weapon system.

- Training takes time and time is money. In an effort to reduce the cost of training, the Navy realized the benefits and began using built-in test and automated test and evaluation equipment instead of individualized hands-on training on "mock up" weapon systems. Technicians are taught to run the diagnostics on test equipment, but are no longer given comprehensive training of actual troubleshooting skills. Combine this ill-trained force with a high operational tempo that emphasizes *fast fixes*, this has produced a culture where technicians are ill equipped to perform rudimentary troubleshooting techniques. Taken further, this produces the possibility that technicians might inadvertently introduce degradation into weapon systems through ill-performed or unnecessary repairs.

- Inadequate visibility of repair components during repair at maintenance facilities, as well as availability at storage locations, often leads maintenance managers to make incorrect decisions regarding maintenance production planning and repair actions. To offset this lack of visibility, non-preferred maintenance actions such as cannibalization, jury-rigging,

and work-arounds are often employed by maintenance managers until an RFI component is received.

- A weapon system is often produced in multiple and incompatible configurations from one lot of systems to the next. This lack of a common configuration is inherently problematic and often unmanageable. Repair of these systems requires sophisticated knowledge of the multiple systems and pin point accuracy when ordering a component for repair. This lack of configuration control directly impacts operational availability.

In response to these problems, logistics and maintenance managers are induced to circumvent the ill-trusted systems by acquiring the components and hoarding them in goody lockers. To the credit of the Systems Command, enormous efforts are underway to address these various issues [Naval Supply Systems Command, 2001; Naval Air Systems Command, 2001].

B.   CROSSBOW SUSTAINMENT CONCEPTS DEFINED

Future operational concepts of weapons platforms such as the CROSSBOW weapon system, defined in the Mission Need Statements (Appendix A and B) as well as the Doctrine for Logistic Support of Joint Operations [U.S. Joint Chiefs of Staff, 2000], Operational Maneuver From the Sea [U.S. Marine Corps, 1996], and Sea Based Logistics [Department of the Navy, 1994], dictates the need to actively evolve logistics and maintenance efforts to support these new strategic concepts.

The selected CROSSBOW sustainment concepts and technologies were validated within the **Precepts** guidelines, with special emphasis that each aspect must enable sustainment through speed, accuracy, acceptable risks, and effectiveness of supportability. While some of the concepts presented are not new in their development, the integration of these currently disparate technologies and methodologies, into a cohesive and aligned strategy, shows considerable promise. The Precepts are as follows.

1.   Autonomic Systems

Autonomic Systems provides an application of information and systems integration technologies that can provide decision makers with accurate and timely information from the battle space. This information technology will improve the ability to see, prioritize, assign, and assess information and resources [Bodnar, 2001].

Autonomic Systems provide the capability to automatically generate and transmit real-time, and near real-time, system performance data from the weapon system to remote stations for processing. Integrated with an internal Prognostic Health Monitoring System (PHM), the Autonomic System will be capable of diagnosing weapon system failures, ordering the spares needed for repair, identify test and repair equipment, schedule technical personnel, and provide the technical data needed for repair [Georgia Technical Research, n.d.].

Additionally, the real-time data is cached in a common database and shared with the transportation authority, tactical and strategic planners, Original Equipment Manufacturers (OEM), and training commands for all levels of weapon system support.

2.   Condition Based Maintenance (CBM)

CBM aims to accurately detect the current state of mechanical systems and correctly predict systems' remaining useful lives. This permits organizations to perform maintenance *only as needed* to prevent operational deficiencies or failures, essentially eliminating costly periodic maintenance while greatly reducing the likelihood of machinery or induced failures.

CBM uses integrated, multi-sensor systems to detect and diagnose emerging equipment problems and to predict how long the equipment will effectively serve its operational purpose. Interfaced with an autonomous processor, the system gathers, fuses, and evaluates real-time data using algorithms that correlate the unique signals to their causes (e.g., vibrations created by a developing fault). The system alerts maintenance personnel to the problem, allowing maintenance activities to be scheduled and performed, as needed, before operational effectiveness is compromised or system failure is realized.

CBM represents one of the most promising developments in the evolution of maintenance practices. As units are increasingly faced with demands to lower maintenance costs, decreased manning, and increased responsiveness/operational readiness, CBM has emerged as a viable alternative to traditional planned maintenance, run-to-failure operation, and the various maintenance approaches between the two extremes [Advanced Diagnostics, 2000].

3. Serial Number Tracking (SNT)

SNT is a "closed-loop" cradle-to-grave tracking of maintenance critical serialized components. [Hayes, 1999] Facilitated by automatic identification technology (AIT) and web-enabled, SNT provides asset and material status not viewable within the current system. SNT will provide:

- full in-transit visibility of assets

- assessments of depot performance

- tracking of usage data

- identification of least effective items for disposal

- simplification of fleet material screens

- accurate track reliability

- accurate tracking of No Fault Found (A-799), erroneously replaced components

- isolation of Integrated Logistic Support (ILS) deficiencies to specific weapon systems/squadrons/personnel

- reduction of carcass loss through business process improvement

- determination of component(s) life usage

- identification of accurate component(s) configuration

- tracking of warranties

Configuration management has long plagued the military services. AIT devices, such as embedded identification assets (Radio Frequency [RF] tags/smart chips/contact memory buttons), can accommodate up to 32K of memory allowing for storage of warranty or maintenance data. AIT will enhance the solutions to configuration management.

4. Distributed Mobile Networks with Intelligent Agents

Distributed mobile networks are made possible by further evolutions in Internet technologies yielding wide-area network capabilities based on component-oriented and dynamic applications [Chen, n.d.]. Using ubiquitous access, or the ability of users to access computing resources from any wireless terminal, deployed units will be able to leverage current industry innovations in distributed mobile networks anywhere in the

world. These new technologies operate using fault-tolerant networks that are robust against electronic attack (redundant transmissions) and secure against intrusion with encryption algorithms.

Intelligent agent based communication applications have shown enormous potential for operating in unpredictable, dynamic environments such as mobile computing networks. An example of a high-level distributed task that might be accomplished by intelligent agents, is the provision for Situational Reports (SITREPS). Major claimants or stockholders (e.g., CINCs, EPMAC, BUPERS, OEMs, Vendors, NAVICP, NAVAIR, NAVSEA) requiring periodic updates of weapon system status, operational status, administrative or personnel information, each would require different aspects of information at different times. The intelligent agent would perform search algorithms, based upon users requirements, and deliver timely information to each user in the desired formatted report.

5. Single Definition Engineering (SDE)

SDE defines a premise of weapon system design providing commonality among weapon platforms and weapon systems. Historically, the acquisition of a new weapon platform often resulted in the complete redesign of major components thus precluding shared configuration between ships or aircraft of different classes or lots. The SDE concept forces standardized commonality of weapon systems [DiLisio, 2001a].

Utilized to enhance innovation not constrain it, SDE would create common architectures of specific weapon systems requiring single supportability and sustainability plans - there by dramatically reducing sparing requirements, configuration management infrastructure, personnel, personnel training requirements, test equipment, and life cycle costs. As with computer software upgrades, weapon system upgrades and improvements would be better accommodated with common system architectures.

6. Life-time partnering of Weapon System Contractors

Lifetime partnering with full, to near full, service contracts provides for technical support from the developer throughout the life of the weapon system. [DiLisio, 2001b] Adversarial relationships, between government acquisition officials, program managers, and weapon system contractors, often disallowed the sharing of technical information

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(proprietary) or the coordinated efforts for weapon system improvement. Partnered Weapon System Contractors, hired under a performance based support criteria, would receive monetary incentives for exceeding the reliability, availability, or maintainability goals. Alternately, failure to reach goals would result in the loss of financial incentives. Technology insertions would also be contracted to ensure modernization of weapon systems at specified target time frames.

7. Modular Weapon System Design

Modular Weapon System Design infers the functional grouping of sub-system components within a unit. This modular component is easily installed in the major system, portable, easily tracked, re-configurable, and easy to troubleshoot. The reduction in repair cycle time, by shortening the Mean Time To Repair (MTTR), is the prime objective. Modularity is not limited to hardware but also applies to software (e.g., software configurable radios).

8. Improved Forecasting and Trend Analysis Tools

Embedded intelligent agents make improved forecasting and trend analysis tools possible. The intelligent agent compares the baseline operating parameters with the data recorded during the last preventive maintenance cycle. Significant deviations from the baseline are noted and forwarded to the maintenance activity for assessment or repair action.

9. Tele-Maintenance

Tele-Maintenance enables remote interface with engineering and maintenance expertise to solve maintenance problems for deployed platforms in real-time [Brown, 2001c]. Web-enabled digital imagery provides distant link capability to remote geographic locations.

10. Labor Saving Innovations

Labor saving innovations to include *paint-less aircraft*, *paint-less ships*, and *robotics* are quickly becoming a reality. In the place of paint, single appliqués, made of polymers and other innovative materials, are applied to the weapon system and cured for semi-permanent bonding. Once applied, periodic inspections are the extent of the labor requirements - dramatically reducing manpower requirements.

Robotics will be used for human tasks that are repetitive in nature, inherently laborious, and mundane in performance. These tasks may include routine housekeeping and food preparation. More challenging tasks may include ballast inspection [The Inside Track, 2000], underway refueling, and aircraft movement (yellow gear services).

The availability of ever improving technology applied to increasingly powerful, and less expensive, computers drives the feasibility of these concepts. Also, the anticipated advances in sensor systems, improvements in diagnostic and prognostic algorithms, and advances in signal processing methods will promote their employment within the CROSSBOW's IOC.

Leveraging use of this technology, CROSSBOW will meet three major objectives: 1) increased operational availability, 2) reduced total ownership cost (TOC) and 3) improved operator and equipment safety.

C.   CROSSBOW SUSTAINMENT FRAMEWORK

1.   Concept and Premise

The CROSSBOW framework is shown in Figure 3. Developed to support the requirements of the Mission Need Statements and within the guidelines of the **Precepts**, this high level framework serves as a functional representation of key supportability concepts considered essential for supporting this future weapon system.

The framework consists of five functional modules representing the foundations required for a successful weapons system deployment. These five modules operate within a C4I (Command, Control, Communication, Computers, and Intelligence) Executive Information System architecture:

- Logistics
- Maintenance
- Personnel
- Training
- Vendor/Contractor

Logistics
Autonomic Environment

- Tailored Logistics packages
- Serial # tracking/TAV
- Independent component order
- Forecasting tools
- Lean Logistics
  - Fast transportation
  - Recognizable processes

TAV database

- Exec system analysis
- Archived data
- Instant transmission to:
  NAVSUP/NAVSEA/
  NAVAIR/NAVTRANS/
  DLA/FISC/TRANSCOM/I
  ndustry Partners

Maintenance
Autonomic Environment

- Prog/diag systems
- Service contracts with industry
- Modular Design
- Technology enabled maintenance
- Lean Maintenance
  - Reduce WIP initiatives
  - Condition Based Maint.

Personnel

- Automated Records Capability
- Improved human resource
  allocation; mix/number/rate
- Personalized QOL initiatives

C4I - Executive Information Systems

- Real-time SITREPS/CASREPS
- OPS forecasting-analysis tools
- Readiness data
- Weapons system status
- Personnel health/status
- Decision Support Systems

Training

- Online/Interactive training
- Manuals available online
- Direct link with schoolhouse
- College courses?

Vendor/Contractor

- Real-time links to OEM for
  technical/engineering support
- OEM real-time visibility or weapon system
  status

Figure 3.   CROSSBOW Framework.

The weapon system operates in an autonomic mode whereby internal/external self-regulating information technologies and communication architectures provide for the automatic transfer and receipt of data and information [Wagner, n.d.].   Autonomic systems will encompass mission areas to include aircraft/ship health, maintenance demand, weapon system status, system safety, and configuration management.

These framework modules interact in the sharing and transfer of data across functional boundaries. A relational database (TAV - total asset visibility database) exists within the nexus of the five modules serving as the primary store of critical mission information. A Decision Support System (DSS), maintained within the C4I environment, will be accessible to all system users yet robust against unsecured penetration.   The Decision Support System assesses the real-time mission data from all sources to provide potential solutions for mission needs. Radio frequency (RF) tags, infrared markers, bar codes, scanners, and identity chips are placed on all critical weapon system components. The serial numbers of these components can be routinely queried by automated scanners and readers, driven by intelligent agents located throughout the pipeline environment, for identification, location, and condition status - creating total asset visibility (TAV) of the component.

2.   Autonomic Logistics Module

The Autonomic Logistics Module encompasses the supportability functions to include the full range of logistics planning. Based upon archived data and current usage data, the Logistics Module would create tailored logistics packages (COSAL/AVCAL) that are configured based upon the platform's mission (e.g., humanitarian, peace keeping, war).   Tailored packages would dramatically minimize volume storage requirements resulting in more efficient utilization of space and capacity with units only carrying what is needed rather than what "might be" needed.

Other capabilities of the Logistics Module would include:

- Autonomic Logistics functions would automatically order components based upon anticipated demand (see PHM), reducing manpower requirements and reducing turn-around time. Autonomic Logistics would provide for enhanced configuration management through real-time status of weapon system Mean Time Between Failure (MTBF) and operational availability.

- Visibility of component status (NRFI, RFI) provided within the TAV environment would focus management efforts and information flow allowing for efficiencies in delivery time frames, intelligent packaging of deliverables, consolidation of inventories, and recognizable processes for re-engineering.

- Determination of provisioning requirements based upon usage trends and storeroom volume availability

- Improved forecasting tools for demand and shipping time frames that would improve management decision-making.

3.   Autonomic Maintenance Module

The Autonomic Maintenance Module encompasses troubleshooting, failure analysis, and repair functions.   It is centered on reliability, or condition based, maintenance practices. The system would be capable of:

- Comprehensive prognostic and diagnostic management of embedded components/systems. Monitoring of critical components and systems would provide real-time information allowing for trend analysis of degraded performance as well as impending failure notification. Enhanced prognostic/diagnostic capability would reduce maintenance downtime, automatically performing fault isolation even in the event of cascading failures.

- Enhanced forecasting for scheduled and unscheduled maintenance activities

- Recommendations for repair actions when RFI components are not readily available (e.g., screen for alternate repair components)

- Embedded links to vendor/contracted engineering services to include failure notifications, engineering service requests, and technical data updates

- Increased support to the technician to reduce mean time to repair (MTTR) using online tele-maintenance, support links, technical databases and virtual manuals

4.   Personnel and Training Module

The Personnel and Training Modules fulfill administrative and personnel related functions. These modules would be capable of:

- Online/interactive training to include *virtual rehearsal* of maintenance tasks, lessons learned cataloging, and task-oriented frequently asked questions. The individual's training would be managed from specialized training (e.g., Corrosion Control) to class "C" technical courses linked to the cognizant naval training command.

- Automated records maintenance and upkeep to include medical, dental, service record, pay and promotion documentation

- Human Resource Allocation. BUPERS' current Job Advertisement and Selection System (JASS) initiative for on-line information and decision system for job placement is but a precursor towards the potential for a more robust, efficient, and comprehensive system for human resource allocation

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- Quality of life issues such as personal customization of embedded intelligent agents to provide communication links, entertainment, and distance learning links to select universities for professional/personal development

5.   Vendor/Contractor

- Provides real-time link to the Prime contractor to enable engineering and technical support

- Enables the Prime contractor to have visibility of real-time performance metrics

6.   C4I Executive Information System

The C4I environment would encompass a Decision Support System utilizing intelligent agents. This Executive System would interface with all functional modules, as well as all major stakeholders, providing real-time data, anticipatory metrics, and suggest *course of action* recommendations. This module would also provide:

- Situational and Casualty reporting

- Operational forecasting for all battle group elements

- Complete weapons system status

- Personnel end strength and force status

- Links to design reference missions combined with an ability to perform strategic planning

7.   Repair Action Walk-Through of Sustainment Framework

The following example is presented to demonstrate the framework's intended capability:

- An airborne unmanned combat air vehicle (UCAV) experiences signal degradation in a power supply module within the armament computer. The UCAV onboard system prognostic/diagnostic sensors detect the degradation and determine, based upon troubleshooting algorithms, the armament computer will fail within 72 hours.

- The impending failure is transmitted, via a data burst, from the airborne UCAV to receiving/transmitting nodes located on the nearest weapon platforms. Because all weapon platforms are outfitted with nodes, the degraded weapon systems can readily transmit their data via the network created by the interconnected weapon platforms.

- The failure data alerts the Autonomic Logistics Module of the need for an impending component replacement. Queries are automatically sent to shipboard storerooms, replenishment ships, defense stocking points, and

the manufacturer, to determine the location of the nearest component, the fastest mode of transportation (if unavailable locally), and the projected delivery time frame along with projected delivery route.

- The failure data, and the resultant logistics information regarding component availability and delivery time, is transmitted to the Autonomic Maintenance Module. The Autonomic Maintenance Module schedules the UCAV for component replacement, other conditional inspections, and notifies the Decision Support System to update the situational status reports. Other lower priority maintenance actions might also be scheduled to include inspecting the "paint-less" appliqué coating of the UCAV – one of the labor reducing applications to reduce required manning on board.

- The appropriate technical shop is alerted of the scheduled repair. If additional troubleshooting is required, repair recommendations are provided "real-time" via satellite link (tele-maintenance) from the manufacturer or from the data library inherent within the Maintenance module.

- The Personnel Module updates the assigned technician's schedule to reflect his/her assignment to repair action. The Training Module notes the technician has not performed this type of repair for some time and recommends *virtual training* for a maintenance rehearsal of the impending repair action. The module notes and records the completed training for future reference. Comparing the statistical performance of the maintenance action against benchmarked data, the Training Module would make recommendations for future training if significant trends persist.

- The Decision Support System, residing within the C4I environment, notes a trend in armament computer failures relating to its power supply. This information is transmitted to the manufacturer and the repair depot for investigation. Trends are also transmitted to training commands for updates in training requirements.

- The component is efficiently delivered within 48 hours making use of a combination of commercial and military carriers linked via the TAV database. The specific component is tracked, using the serial number of the asset, to identify and maintain accountability as the component travels through the pipeline. Also employed is radio frequency (RF) tagging to redundantly track the asset as well.

- The component is installed by the technician and the status of the aircraft is instantly updated using his Personal Display Unit. The Logistics Module notes the completion and awaits the NRFI carcass for turn in. The Maintenance Module notes the repair and updates the aircraft database of the specific UCAV. The C4I Decision Support System notes the repair for the Situational Report of the squadron aircraft – providing the area commander real- time status of his available assets.

8. Can the DON Realize the Crossbow Sustainment Framework?

Is the integration of the suggested individual concepts and technologies realizable within the CROSSBOW weapon system? Current research and development initiatives in the DD-X, the Joint Strike Fighter, and AAAV [Mack, 2000] weapon system programs suggest the answer is yes to the capability. However, Navy and DOD cultural issues negatively restrict the implementation of new technologies and methodologies (discussed later in this analysis).

Corollaries exist in the business community that provide insight to the achievability of incorporating the suggested CROSSBOW sustainment concepts into a cohesive and synergistic system.

The *TRADENET* system is an electronic data interchange (EDI) system that allows wireless computer-to-computer exchange of inter-company business documents and information [President and Fellows of Harvard College, 1990]. Based out of Singapore and designed by IBM and Computer Systems Advisers, Pte. Ltd., the TRADENET System streamlined the procedures and protocols of many different agencies and organizations into a set of coherent and simplified data architectures. More of a systems integration effort than a systems building effort, TRADENET performs semi-autonomous functioning to facilitate document generation, data analysis, performance algorithms, financial transactions, and resource allocation.

With the implementation of TRADENET in 1989, turnaround time for processing documents and queries dropped from four days to as little as 15 minutes. Significant logistic improvements were noted as well in material deliveries, the scheduling of delivery trucks, equipment, and manpower usage. International users of the system reported savings of 25% to 35% achieved in the more efficient handling of trades and documentation.

TRADENET architectures are now being employed as a *value added network* throughout the Singapore economy. Singapore's *Intelligent Island* concept will extend the TRADENET architectures to inter-bank services, health care administration, legal, retailing, and manufacturing [President and Fellows of Harvard College, 1994]. A

healthcare module called MediNet will wirelessly link hospitals, laboratories, pharmacies, drug distributors, private clinics, and medical supply companies. The vision is to extend the use of EDI to every sector of the Singapore's customer base to create a common commerce environment for conducting business.

Though the requirements of TRADENET and the Department of the Navy logistics are inherently different, the similarities between the systems are striking:

- Each system requires support for a large and geographically dispersed customer base with differing needs and requirements.

- Each system requires time sensitive data to support different customers in desired formats

- Each system requires the tracking, coordination, and planning of resources

- Each system requires coordination between individual organizations to perform necessary functions

- Each system requires autonomous actions to achieve efficiencies

This example provides an indication of the technology available now that is achieving exponential increases in system efficiency. The Navy faces the greatest challenge of becoming the *Navy of Tomorrow* if effort is not made to pursue these proven technologies.

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III.   SEA ARROW COST ANALYSIS

A.   INTRODUCTION

This section will determine the projected life cycle cost (LCC) of the CROSSBOW UCAV (SEA ARROW) as well as the logistics support vessel (SEA QUIVER). Analysis will include determination of the systems cost drivers and the potential of the CROSSBOW sustainment concepts to mitigate cost inefficiencies. The methodology for costing will only be discussed in terms of the SEA ARROW. However, cost calculations and a cost summary for the SEA QUIVER are discussed in Appendix E. The analysis concludes with the total life cycle cost of 600 SEA ARROWS over 20 years at $13.3 billion dollars. The total life cycle cost of 2 SEA QUIVERS over 20 years at $1.9 billion dollars.

Using Visibility and Management of Operating and Support Costs (VAMOSC) Cost Analysis Improvement Group (CAIG) F/A-18 systems cost data as a representative baseline - changes were imposed upon a simple parametric life cycle cost analysis (LCCA) Excel spreadsheet to reflect the systems and systems costs inherent within a UCAV platform. The data used in this analysis was acquired from NALDA [Naval Aviation Logistic Data Analysis, 2000a] Program and VAMOSC CAIG databases [Visibility and Management of Operating and Support Costs, 2000].

The NALDA data encompassed over 524,060 flight hours flown in 4 years (April 1996 - March 2000) and provided input to the parametric model with regard to the Mean Flight Hours Before Failure (MFHBF). The NALDA F/A-18 data contained 4,557 line items made up of five-digit Work Unit Codes (WUC) for each system on the F/A-18C. A WUC is defined in the OPNAVINST 4790.2H as; *a numeric or alpha/numeric code that identifies a system, subsystem, set, major component, repairable subassembly, or part of an end item being worked on* [Naval Aviation Maintenance Program Manual, 2001].

The VAMOSC-CAIG template data was accessed for Fiscal Years (FY) 1988 - 2000. This data primarily provided costs of the F/A-18C weapons system for comparison and validation against the parametric cost spreadsheet model cost figures. The

VAMOSC - CAIG template was segregated in cost elements from FY1988 to FY2000. The VAMOSC data reference manual defines this cost element grouping as an Aviation Type Model Series Report (ATMSR), that contains cost and non-cost elements for Aircraft Type/Model/Series by fiscal year. Data elements are identified and developed to display meaningful operational statistics for each Type/Model/Series (T/M/S) that are recorded by flight hours during the fiscal year [Price, Waterhouse, Coopers, 2001]. This data was assembled and displayed by Major Commands that managed aviation operations.

The structure of the ATMSR reports costing at seven distinct levels: Organization Level (1.0 series), Intermediate Level (2.0 series), and Depot Level (3.0 series), Training Support (4.0 series), Recurring Investment Costs (5.0 Series), Other Functions (6.0 series), and Contractor Logistics Support (7.0 series). The ATMSR also provides several non-cost metrics against which cost elements could be evaluated. These non-cost metrics included Aircraft Numbers and Annual Flying Hours. Additionally, there is a new section of the ATMSR titled "TMS Metrics". This section provides Navy-wide Average Age Year - End and Average Flight Hours in Life Year - End for each T/M/S reported in the ATMSR.

B.   BACKGROUND

LCCA has been performed in various DOD programs in an attempt to capture all life cycle costs associated with a particular weapon system. These cost estimates prove invaluable in determining initial acquisition purchase quantities and procurement development plans, particularly within constrained budgetary environments. In Life Cycle Costing, there are many techniques that can be used to estimate the cost of a future yet-to-be-developed system:

- *Engineering estimation* is a method by which every item in the system is detailed and a dollar cost is associated with it

- *Analogy estimation* takes historical costs from one system and adjusts them to assimilate the intended parameters of the unknown system

- *Expert opinion* relies upon the knowledge of an expert in the field, and from that opinion an estimation is derived

- *Delphi method* is more robust than expert opinion. Consensus of many experts can be brought together to form a single determination

- *Extrapolation* uses data derived from an existing and comparable system that is adjusted to meet the parameters of the proposed system. The generated data, derived from the original system data, is determined with the assumption that it will act in a manner similar to the original system's performance parameters.

- *Parametric analysis* employs equations that describe relationships between cost, schedule, and measurable attributes of systems, hardware, and software. The equations contained within the model attempt to describe how a product's physical, performance, and programmatic characteristics affect its cost and schedule. These equations are often integrated into pre-derived software tools or formulated into an Excel spreadsheet [Loftus, 1999].

Examples of current LCCA software tools include FleetSight from Decision Dynamics, used in analysis of the P-3 Orion and SH-60. Web-LCCA software, from Litton TASC, was used for costing the LANTIRN and PHALANX Close In Weapon System (CIWS).

These software applications are very useful for developmental systems with attributable component reliability and system information. CROSSBOW, in its current conceptual infancy, does not provide the comprehensive data required for the full implementation of these proprietary models. However, a simplified academic spreadsheet model was obtained that provided reasonable calculations of costs despite the limitations of available CROSSBOW data [Junge, 2000]. This model made use of parametric analysis, extrapolation, and analogy estimations to derive quantifiable and viable cost assessments.

C.   LIMITATIONS

In the establishment of the F/A-18C baseline cost data from NALDA, the difference between priority maintenance actions (e.g., Partially Mission Capable (PMC), Not Mission Capable (NMC)) could not be delineated. All data was therefore, considered in worst-case scenarios of Not Mission Capable status.

VAMOSC F/A-18C baseline cost data did not account for the cost of producing the aircraft or the costs associated with the length of time for a production run. The parametric model used in the analysis accounted for the production costs, which produced a higher and more robust cost estimate than VAMOSC cost figures.

NALDA data was an aggregation of O and I level maintenance actions (MA) and Mean Time To Repair (MTTR). Without exhaustive effort to separate the documented maintenance actions, there was no way to determine what times to repair could be attributed to each level of maintenance.

While RDT&E is realistically an ongoing program throughout the life of a weapon system, only four years of RDT&E cost was considered in the development of the SEA ARROW system.

D. METHODOLOGY

1. Developing the Baseline Model

The VAMOSC CAIG template data for the F/A-18C was downloaded from the VAMOSC website and transferred into an Excel spreadsheet for analysis. A partial example of the template format is seen in Figure 4.

Aircraft TMS	Element Number	Element Description	1988 ($K)	1989($K)
		Year number	1	2
F/A-18C	1	**Subtotal Organizational Costs**	**32590**	**88273**
F/A-18C	1.1	Subtotal Organizational Personnel Costs	21472	44684
F/A-18C	1.1.1	Organizational Military Personnel Costs	21472	44684
F/A-18C	1.1.2	Organizational Civilian Personnel Costs	0	0
F/A-18C	1.1.3	Organizational Contractor Personnel Costs	0	0
F/A-18C	1.2	Subtotal Organizational Operations Costs	11118	43589
F/A-18C	1.2.1	Temporary Additional Duty Costs	132	0
F/A-18C	1.2.2	Training Expendable Stores Costs	1830	6131

Figure 4.   Example of Partial Elements in the CAIG Cost Template.

It was found that the CAIG templates varied in element format, whereby some elements had been modified according to the FY that was being analyzed. The elements, that were the same, were grouped as such: FY1988-1991, FY1992-1993, FY1994-1997, FY1998-1999 and then FY2000.

After FYs were grouped according to common element descriptions, the element costs were then totaled by FY column in the *Total* row of the spreadsheet (as seen in Figure 5) and discounted using a 10 percent rate in the formula:

$$\text{Total FY \$}/(1+\text{Discount rate\%})^{\text{Year number}}$$

The *Total* row was then added to the *Discounted cost* row to derive the *Cumulative discounted cost* row.

Year number	1	2
Total ($)	$46,563,000.00	$141,932,000.00
Discounted cost	$42,330,000.00	$117,299,173.55
Cumulative discounted cost	$88,893,000.00	$259,231,173.55

Figure 5.   Example of the Element Total, Discounted and Cumulative Discounted Costs.

The *Cumulative discounted cost* row for each FY column was then totaled to equal an overall FY1988-FY2000 total LCC that established another baseline for comparison with the parametric F/A-18C baseline spreadsheet and against the UCAV parametric analysis spreadsheets.

2.   Developing the Parametric Model

The F/A-18C baseline data, for eventual use in the simplified academic worksheet model, was obtained from NALDA and loaded into pre-constructed excel worksheets labeled *Raw F/A-18 Data*, *F/A-18 Filtered data – formulas*, and *UCAV Comp*. The *Raw F/A-18 Data* columns were totaled and summarized. The *F/A-18 Filtered data –formulas* worksheet contained edited data from the *Raw F/A-18 Data* sheet that eliminated unidentified WUC's. An example of this worksheet whci as seen in Figure 6.

WUC	NOMENCLATURE	MFHBF	Fail (4yrs)	Failures/YR	MFHBMF	V-FAILS	MTTR	MMH/MA	MMH	MMH-FH-O	MMH-FH-I
03****	MAINTENANCE INSPECTIONS	87343.33	6	1.50	104812.00	5	7.87	2.84	1063467.5	5.61586	0.00095
04****	CORROSION PREVENTION	262030.00	2	0.50	262030.00	2	4.87	2.12	363749.2	1.58839	0.00637
05****	GENERAL FUNCTIONS	30827.06	17	4.25	30827.06	17	6.77	1.77	110908	0.08057	0.00031
09****	NON-AERONAUTICAL WORK	8734.33	60	15.00	9035.52	58	3.51	2.67	9753	0.00164	0.00080
11****	AIRFRAME	6.69	78322	19580.49	6.77	77416	5.17	2.38	481231.2	1.83068	0.07293
12****	FUSELAGE/COMPARTMENTS	140.95	3718	929.50	152.21	3443	2.86	1.60	201151	0.05623	0.01946
13****	LANDING GEAR SYSTEMS	10.35	50643	12660.67	11.36	46131	5.64	2.88	340697.3	0.91795	0.77381
14****	DIRECTIONAL FLIGHT CONTROL SYSTEMS	13.11	39973	9993.26	14.64	36804	9.40	3.86	321600.5	1.02986	0.43773
17****	ESCAPE SYSTEMS	55.21	9492	2373.01	59.74	8772	2.73	2.06	51873.1	0.10520	0.07485
	Subtotal	171.10	182147.73	45536.93							
24****	AUXILIARY POWER PLANT (AIRBORNE)	124.92	4195	1048.75	162.10	3233	7.59	3.84	28871	0.10216	0.03545

Figure 6.   NALDA Baseline Spreadsheet Example (F/A-18 Filtered Data).

This reduced the number of line items to 2,700. The data was then aggregated at the two-digit WUC system level. The result was 39 two-digit WUC subdivisions. The data in the Mean Flight Hours Between Failures (MFHBF) and FAILURES columns were then totaled for each two-digit WUC category. This worksheet also contained formulas that calculated the two-digit MFHBF and weapon system MFHBF by dividing the total number of flight hours (524,060) by the number of failures for each two-digit WUC. The totals of the calculated MFHBF and FAILURE columns were also computed. The third worksheet *UCAV Comp* was developed to show the systems that would be eliminated from the F/A-18 data to assimilate the UCAV characteristics (extrapolation). The MFHBF and FAILURE columns were then recalculated for each two-digit WUC. The total flight hours (524,060) was then divided by the resulting numbers in the two-digit WUC FAILURE column to calculate a UCAV MFHBF for each of the two-digit WUC systems and weapon system MFHBF.

Developed by an Aerospace Engineering student at Naval Postgraduate School, the parametric model was designed with eight linked worksheets; *User Inputs, Manning,*

Training, RDT&E, O&M, Totals, Graphical Summary, and *Poisson Table.* Figure 7 provides a graphic representation of the data flows of the parametric model.

a. User Input

The User Inputs worksheet provided the link to the various system, personnel, and equipment parameters. It was divided into eight categories; general fiscal and attrition rates, operational consumption and operating time, manning, maintenance and equipment, training, research and production, and components.

b. Manpower

This section of the parametric model focused on the total manpower costs for Officers, Chief Petty Officer's (CPOs) and Enlisted at the O, I and Squadron Headquarters levels. This cost worksheet was divided into four sections, the Required Manning Levels, Individual Salary calculations, FY Inputs section (formatted by FY number and by corresponding program year number), and Totals for Squadron, I-level, and Squadron Headquarters.

c. Training

This section of the parametric model focused on the total training costs for the Officer, CPO and Enlisted at the O, I and Squadron Headquarters levels. This cost worksheet was divided into three sections; the training cost of the individual, number of personnel that require training, and the funds required for training.

d. Research, Development, Test and Evaluation (RDTE)

The RDTE and Production worksheet was divided into seven sections labeled: *FY* Inputs, UAV Attrition Information, Production Line Open Costs, Ground Equipment Information, Development Costs, Production Costs, Total Development and Production Costs. This worksheet illustrated RDTE costs that were associated throughout the program's life cycle from initial system development to Follow-On Test and Evaluation (FOTE).

Input Data

General Inputs

Training Inputs

Operational Inputs

Manning Inputs

Maint & Equipment Inputs

RDTE & Production Inputs

2-digit WUC Inputs

WUC Reliability Inputs

User Input Data

WORKSHEETS

Manpower

- Required manning
- Salaries by activity

Training

- Personnel requiring training
- Funds required for training

Operations and Maintenance

- Required Spares
- Maintenance Cost
- Initial Spare Purchase
- I-Level Activation cost
- I-level Operation cost
- Transportation Cost
- Fuel/POL cost

RDTE & Production

- Production Line Open cost
- Ground Control Equipment
- Development Cost
- Test Equipment Cost
- Total Production Cost
- Total RDTE Cost

Formulas

- Failure Rate (λ)
- MTBF ($1/\lambda$)
- Required Spares ($\mu = k\lambda t$)
- Spares Purchased (μ * unit cost)
- Annual Maintenance Costs
- Training Costs
- Present Value
- Inflation Rate

Logical Functions

- IF – THEN Excel functions
- Ceiling Excel functions

TotalsWorksheet

Manning	Training	RDTE	O&M
Inflation	Present Value	Cumulative PV	
O&M/squadron	LCC per squadron		

Figure 7.   Parametric Model Graphic Data Flows.

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e. Operations and Maintenance (O&M)

The O&M worksheet was developed to estimate the number of required spares, annual maintenance costs, initial spare purchase cost, Intermediate level activation and operations cost, transportation cost from the Organizational level to the Intermediate level, and Fuel (e.g., petroleum, oil, and lubricants) cost. Each of these areas was used in determining the LCC of the air vehicle O&M.

f. Totals

The Totals worksheet took the formulated cost from each functional worksheet (Manpower, Training, RDT&E, etc.) and placed them, by fiscal year, so that computations of inflation, present value, and net present values of the investment could be determined. The culmination of all costs was summed to produce a total life cycle cost for the systems.

g. Poisson Table

The Poisson Table worksheet was used in conjunction with the calculation for component sparing (O&M) while the Graphical Summary presented the data pictorially.

The input requirements of each worksheet are now briefly discussed. Detailed descriptions of the worksheets, inputs, and analysis are provided in Appendix D.

E. SUMMARY

1. <u>The total life cycle costs for 600 SEA ARROWS over 20 years equated to $13.3 billion dollars. The total life cycle costs of 10 SEA QUIVERS over 20 years equated to $7.7 billion dollars.</u>

2. <u>Parametric modeling, extrapolation, and analogy cost comparison provided a reasonable depiction of cost data despite the lack of actual system data.</u>

The benefit of analogy cost comparison and extrapolation, within a parametric model spreadsheet, was a reasonable depiction of the potential life cycle costs associated with a notional unmanned combat aerial vehicle (UCAV). Without actual system data within a fielded system, accurate costing can be difficult to determine.

Parametric modeling, extrapolation, and analogy estimation proved easy to use, verifiable in calculation, and robust in ability to manipulate and process relational data.

3.   <u>O&M costs proved to be the significant drivers of cost within the model. Second in cost magnitude were associated manpower costs.</u>

Historically, the greatest cost drivers of weapon systems have been the Operations and Maintenance and Manpower costs [Smith, 2001]. This analysis supported the assumption in both the UCAV and F/A-18C models. The UCAV O&M was 49 percent of the total cost, while the F/A-18C O&M was 61 percent of the total cost. Manpower was second in cost magnitude in both models with 32 percent for the UCAV and 19 percent for the F/A-18C.

4.   <u>The reduced flight-hours requirements for UCAV proficiency training produced substantial reductions in O&M costs.</u>

Within the O&M category, the factor that primarily affected costs was the reduction in monthly operating hours. When the hours in the model were reduced from 29.9 hours per month in the F/A-18C to 10 hours per month in the UCAV (reduced to reflect less flights required for training), the overall LCC decreased by $4.29B over 20 years. It was found that this cost reduction took place because the *numbers of spares required were significantly less* with the reduction in flight hours.

The proficiency training would be accomplished on the Ground Control Equipment (GCE) trainer precluding the need to actually fly the air vehicle. As UCAV in flight operations does not involve a hands-on aircraft interface, the UCAV operator gains the same quality of proficiency training through simulation on the GCE. In contrast, with a piloted system, the pilot must be airborne in order to achieve the most realistic training and, as a result, increases the LCC with the need for more parts, fuel, and maintenance. However, GCE usage would invariably increase, to accommodate this enhanced training requirement. Therefore it becomes essential to design the GCE with higher reliability and a low cost of repair.

5. **The UCAV's reduced requirement for performing flight for training reduced repair requirements throughout the repair pipeline - lending to consideration of eliminating intermediate level repair.**

The reduction in flight hours by almost 1/3 of the current operational time lends itself to consideration that the I-level system could be eliminated or reduced onboard the logistics support ship. Reduced flight hours translated into less maintenance actions that inferred a reduced I-level or a direct O-level to Original Equipment Manufacturer (OEM) logistics pipeline might be undertaken. With the implementation of a direct O-level to OEM methodology, the idea of a truly centralized Inventory Control Point (ICP) for the UCAV support infrastructure could be entertained. This concept would require a robust interface between commercial carriers and military transport as well as improvements in the interface between the current Navy ATAC and DOD transportation system.

6. **Improvements in repair turn around time, at the repair facilities, displayed a larger cost impact than improvements in system reliability.**

Maintenance costs were not driven as much by reliability as initially assumed. In the parametric analysis, maintenance costs were largely impacted by the repair turn-around-time of degraded components at the Intermediate and Depot levels of repair. While improvements within a weapons system's reliability are an important component of availability, Intermediate and Depot level maintenance affected costs more dramatically with improvements in the repair Turn Around Time (TAT). Enhanced repair capabilities were considered possible with the proposed implementation of a Prognostic Health Monitoring system within an autonomic environment.

7. **Reassignment of RDT&E costs to the contractor, through enhanced DOD partnership initiatives, reallocates risk**

While not directly assessed within the parametric model, current efforts to transfer RDT&E costs shows considerable promise for long term cost savings. Some of the RDTE costs might be deferred from the DOD budget through enhanced Defense Advanced Research Projects Agency (DARPA) research partnerships with civilian aviation industry contractors [Defense Advanced Research Projects Agency, 2001].

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These projects are already underway with real-world UCAV and UAV projects and have produced significant RDT&E cost savings.

8. <u>Prognostic Health Monitoring (PHM) systems within the Autonomic structure showed significant benefit in LCC improvements.</u>

The model showed the potential LCC benefits of a Prognostic Health Monitoring System through the demonstrated cost savings. Other findings, and potential benefits of the PHM systems, were the anticipated reductions in NRFI backlogs at the O, I, and D-level with the improvements in troubleshooting and a reduction in A-799 (non-duplicative component discrepancies) [Brown, 2001e]. With the elimination of redundant troubleshooting of elusive problems, wasted man-hours at O, I, and D-level would be dramatically reduced. These additional man-hours would translate into increased man-hours for other requirements at the squadrons and repair facilities.

The logistics TAT would also be improved through the fault anticipation modes of the PHM system. The requisition for the failed component could be replaced *Just-in-Time* rather than *Just-in-Case*, eliminating costly component spares inventories onboard the ship.

Reductions in cannibalization would also be produced with real-time diagnostics of impending component failures. A replacement component could be identified, shipped, and received before the component actually failed.

9. <u>Cost per squadron of the UCAV was on average 40 percent less when compared to the cost per squadron of the F/A-18C.</u>

- UCAV manning was 29 percent of the F/A-18C manning cost
- UCAV Training was 52 percent of the F/A-18C training cost
- UCAV RDT&E was 55 percent of the F/A-18C RDT&E cost
- UCAV O&M was 27 percent of the F/A-18C O&M cost

F. CONCLUSIONS

The CROSSBOW weapon system would benefit from extensive use of Life Cycle Cost modeling. LCCA illuminates the real cost drivers that predominate the budget of any weapon system. O&M and manpower costs were identified as significant cost

drivers of this system. Our analysis highlighted the number of modeling programs available as well as *areas of opportunity* for long-term cost efficiencies within the CROSSBOW weapon system. Areas of opportunity include:

- Reduced flight hour requirements of the Unmanned Aerial Vehicle (UAV/UCAV) drove the maintenance, manpower, and training cost down. The caveat to this development is the increased use of the GCE introducing increased LCC cost for this subsystem.

- The potential reduction in maintenance actions, coupled with a robust logistic pipeline suggested the potential reduction, or removal, of I-level repair.

- Reduced repair turn around time at the O, I, and D level facilities, facilitated by PHM, produced higher returns than increased reliability of the component.

Perhaps the most telling aspect in the LCCA was the number of aircraft that could be purchased at 30 percent of the LCC of the F/A-18C. The O&M costs of the SEA ARROW were only 27 percent of the total LCC of the F/A-18 despite the additional 240 aircraft. Given these results, it was found that the overall LCC reductions made the UCAV a more cost effective option for most missions and wartime scenarios. This idea operates under the premise of using the less costly Hyundai (SEA ARROW) for the less intricate missions while the BMW (F/A-18C) would be used for complicated missions with a high price associated with failure.

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IV. MODELING AND SIMULATION OF THE REPAIR CYCLE

A. INTRODUCTION

Recent advances in *modeling and simulation* programs show substantial promise in influencing current sustainment methodologies and paradigms. Simply stated, a model emulates the actions and outputs of an actual system. Simulation is the art and science of constructing a model and performing tests upon the model to determine impact and effect. This proves very useful, as conducting direct experimental analysis on an existing sustainment system is obviously infeasible. Simulation also provides the advantage of time. Many simulations can be run which replicate days, weeks, or years of activity - providing tremendous flexibility in analysis.

Using Arena 3.0 Simulation tools, this analysis determined that <u>an increase in efficiencies imposed upon a baseline model produced an optimal range in Operational Availability of 77 to 86 percent. The optimal range serves as a target for the implementation of new technologies and methodologies.</u>

The effort of this research was two fold: to provide a quantitative assessment of selected CROSSBOW logistics and maintenance concepts (discussed in Chapter II) to illustrate the potential influence of the concepts in a graphical manner. It will also show the usefulness and potential of modeling and simulation tools when conducting research such as the CROSSBOW project.

B. OBJECTIVE

This analysis is predicted to identify specific areas, within the current sustainment structure, which could be improved upon to reduce the replenishment and repair cycle time for the optimization of any weapon system - not just the CROSSBOW weapon system.

The modeling and simulation methodology used in this research will:

- Create a baseline comparator by simulating the current component repair methodology - from the removal of a component from the weapon system to the shipment of the component to a Designated Overhaul Point (DOP) for eventual repair

- Simulate a repair flow to emulate incrementally imposed efficiencies achieved through the CROSSBOW sustainment concepts
- Simulate a repair flow to emulate incrementally imposed efficiencies achieved through increased reliability of system components
- Assess the impact of the purported efficiencies against the baseline model for significance

The significance of reducing replenishment and repair cycle time and increasing system reliability is critical for two key reasons. First, the timely requisition, replenishment, and repair of a failed weapon system are essential to operational readiness and sustainability. Secondly, because the high unit cost of depot level repairables (parts that are found economical to repair instead of discarding and replacing with a new unit), drives significant inventory investment as a result of the extended length of the repair cycle time [Kiebler et al, 1996].

C.   SCOPE AND LIMITATIONS

It should be noted that the repair pipelines, and the processing of aviation components (AVDLR) and surface combatant components (DLR), are characteristically different in the routing of NRFI assets to DOPs as well as IMA methodology. However, this modeling simulation was designed to represent the general repair process flow (evident in both repair pipelines) for a given component to illuminate potential efficiencies that result from the CROSSBOW sustainment and maintenance concepts - and was not designed to perfectly mimic the existing systems.

While dependency in probability failures might be evident within the model, independence was assumed with an established distribution of failure probabilities for simplification of analysis.

It is important to note the distributions and process times were compiled primarily from NALDA data [Naval Logistics Data Analysis, 2000b]. While model validation and a screening process were performed on all data used, time limitations in analysis did not allow a robust assessment of all variables. Therefore, further use of the models should only be performed with additional validation.

The constraints involved in the software limited the creation of simulation entities to 150. This constrained the aggregate number of spares and NRFI items, either in the

maintenance cycle or enroute for off ship repair, and was the driving factor behind limiting the number of operable aircraft to ten.

D.   METHODOLOGY

Operational Availability (A_o) is defined as the probability that a weapon system, when used under stated conditions in an actual operational environment, will operate satisfactorily when utilized [Blanchard, 1992a].

A_o can be mathematically expressed as:

$$A_o = MTBM/ (MTBM + MDT)$$

Or

$$= Uptime/(Uptime + Downtime)$$

where:

- MTBM (mean time between maintenance) = $1/(MTBM_p + MTBM_c)$ (or $1/(1/\lambda + 1/fpt)$ where λ is the failure rate and fpt is preventive maintenance rate)

- MDT (maintenance down time) = $M + LDT + ADT$; or the total elapsed time required to repair and restore a system to full operating status

    - M (mean active maintenance) is the mean or average elapsed time required to perform scheduled (preventive) and unscheduled (corrective) maintenance. Also expressed as Repair Turn Around Time (RTAT).

    - LDT (logistics delay time) is the maintenance down time expended waiting for a spare part to become available, awaiting transportation, waiting for a maintenance facility, etc. LDT typically comprises the largest portion of MDT.

    - ADT (administrative delay time) is the maintenance delayed for reasons of an administrative nature (e.g., personnel assignment, log book entries).

Examining the equation for A_o, increases in MTBM can influence the equation towards increased system readiness yielding a higher quantity of fully mission capable aircraft per given period. This can considered as increasing the reliability of the system. Additionally, any *decreases* in MDT will also increase A_o to more gainful levels of

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availability. A decrease in MDT is synonymous with reducing logistics and repair cycle time. Given this relationship, MDT can be viewed as directly impacting the quantity of fully mission capable aircraft per given period.

As such, the model was computationally formatted to report A_o in terms of the ratio of fully mission capable assets to the total authorized allowance (FMC/Total Aircraft Allowance).

With a baseline model constructed, representing the current component cycle from system failure to system repair, the CROSSBOW concepts were superimposed upon the model. These modifications were performed in <u>four separate and distinct methodologies.</u> The first method represented efficiencies through decreased process times (LDT and ADT) of component sustainment. The second method represented efficiencies by decreasing repair turn around time in the maintenance process (mean active maintenance). The third method represented efficiencies through decreasing both maintenance and process times in equal increments. The fourth method investigated the effects of increased component reliability. Individual functional modules were identified as supply, maintenance, or weapon system performance simulators by nature. These modules were then incrementally improved in efficiency to determine the impact. Each incrementally improved simulation result was graphed to determine an optimal range of efficiency within each model. The optimal range represented a target, for technologies, methodologies, and reliability drivers that should be sought for maximum gains.

The focus, in each scenario analyzed, was upon system operability factors, manifest from improvements in MDT. These factors included:

- System Down Time
- Total Flight Hours (flown)
- Total Failures
- Operational Availability (A_o)

The specific design scenarios included:

- Scenario One: Baseline Model of current sustainment methodologies.

- Scenario Two: Process Scenario emulating the concepts of autonomic logistics and serial number tracking. This scenario will concentrate on the sub-variables LDT and ADT.

- Scenario Three: Maintenance Model emulating the concepts of autonomic maintenance systems, CBM, PHM, improved forecasting and trend analysis, tele-maintenance support, modular system design, and labor-saving initiatives. This scenario will concentrate on reducing the sub-variable M.

- Scenario Four: Assessment of the cumulative impact of combining both process and maintenance improvements for impact.

- Scenario Five: Reliability model assessing the impact of increased weapon system reliability. This model compares a change in the total system reliability against a change in the top two high failure components.

Not all of the concepts presented in Chapter II lends to the modeling and simulation technique. These concepts included Distributed Mobile Networks with Intelligent Agents and Life Time Partnering with Weapon System Contractors. The pronounced merit of these methodologies is promising and should be considered for further analysis using alternate techniques.

E.   PRESENTATION OF SCENARIO MODELS

The flowchart (Figure 1) served as a sounding board and a validation tool for the construction of each model. With the construction of a flow chart, the baseline model (Scenario 1) was designed to generally replicate the conditions, performance, and outputs of this current repair process. The number of RFI spares was held constant throughout the analysis for simplification of assessment. The actual level of sparing used in the baseline was determined by calculations in the LCC model.

Program logic, descriptions of the model modules, distributions, and process times are provided in Appendix F. Each scenario was incremented and run through ten iterations encompassing 6000 hours for each change to assess variability and impact. Results from the ten iterations were then averaged and used for comparison against the baseline. The averages were graphed using spreadsheets which are provided in Appendix G.

1.   Scenario One: Baseline Model

The baseline model produced the following operability factors (averages) for 10 aircraft during 6000 cycles (hours):

Down time per weapon systems:	23.07 hours
Total flight hours per squadron:	974.9 hours
Total failures per squadron:	327.4
Operational Availability:	74.58 percent

The beginning of each simulation was initialized by placing all weapon systems into a fully operational state. Integrating aspects of the NALDA logistics data, the simulation modeled 10 fully mission capable aircraft flying one hour per day for 250 days (6000 simulations ÷ 24 hours per day). Since each aircraft was scheduled for one flight per day, the aircraft could achieve a maximum of 250 flight hours in a 6000 hour period or 2500 flight hours per squadron. The level of total flight hours per squadron typically fell between 875 to 1625.

A 35 percent probability of component failure was assigned to establish a failure pattern. Component failure was calculated using the following steps:

- Determination of the MTBF for each associated subsystem (NALDA)

- Calculation of the subsystem failure rate ($\lambda_{component}$ = 1/MTBF)

- Calculation of system failure rate $\lambda_{sys} = \sum_{i=1}^{k} \lambda_{component(i)}$

- Calculation of system reliability ($R_{sys} = e^{-\lambda t}$)

- Calculation of the probability of failure as (1-R_{sys})

Based on the NALDA data, the baseline system reliability was 65 percent while the probability of a failure was 35 percent. The following summaries outline the module functions within the model.

a.   Initialize Squadron

This module initializes all systems to a fully mission capable state. Initiates flight operations (cycles) at one hour per flight.   Introduces a 35 percent probability of component failure. FMC aircraft are delayed 23 hours before next flight.

b. Assign Type Failure

Assigns one of seven component failures based upon NALDA failure rates for one-digit WUC aggregates. An eighth component failure, for ground terminal equipment, is assigned based upon MTBF data [Kasal, 1999].

c. O-Level Repair

Contains module subsets for the general repair actions (component removal, replacement, inspections and minor repair) to return the aircraft to service. Subset modules include:

- Replace Part at Squadron
- Return aircraft to service after 23hr delay

d. Initialize AVCAL Allowance

Establishes sparing levels for eight components. The initialized spares are stored in a rotable pool for issue.

e. Screen for Repair

Contains module subsets, which determine level of repair action and routing to appropriate repair activity. Subset modules include:

- Route to Squadron Shop
- Route to IMA by part type
- Route offship for major repair

f. IMA Repair

Repair shops performing corrective actions on components to achieve ready for issue status. RFI material is routed to the pool for storage and re-issue.

g. Ship NRFI DLR for Major Repair/Replacement

Average logistics time frames for shipment of NRFI components through the ATAC system, to the DOP for repair, and eventual storage after repair.

2. Scenario Two: Process Delay Time

It was assumed that all efficiencies introduced by reducing process delay times applied to the whole system. As such, a scaling factor was introduced that would allow a single change to increment percentage increases or decreases into the process delay times at all levels. Using decrements of 5 percent, the process delay times were subsequently

reduced. Optimal weapon system operability was attained within a reduction range of 15 to 25 percent of LDT and ADT (Figure 8). Operability factors were as follows:

Down time per weapon systems:	21-23.6 hours
Total flight hours per squadron	966-986.3 hours
Total failures per squadron:	338-339
Operational Availability:	74.3-76.7 percent
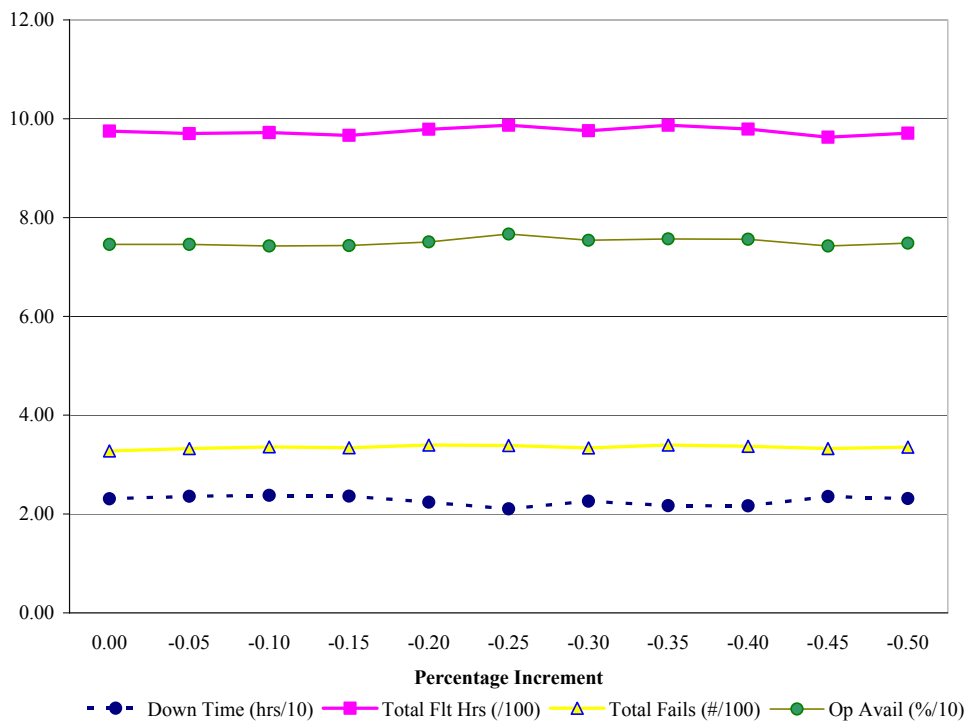
Figure 8.   Chart of Adjustments in Process Delay Times.

3.   Scenario Three: Maintenance Time

Using the same method for scaling as used in process delay times, the maintenance model was decremented in steps of 5 percent. Optimal weapon system operability was improved as MTTR was reduced in 5 percent decrements as shown in Figure 9. The steepest aspect of the curve (slope) occurs between 15 and 30 percent indicating the greatest rate of efficiency gained for an optimal range. Operability factors were as follows:

Down time per weapon systems: 11-16 hours
Total flight hours per squadron   1003-1090 hours
Total failures per squadron   357-376
Operational Availability: 80.8-86.2 percent
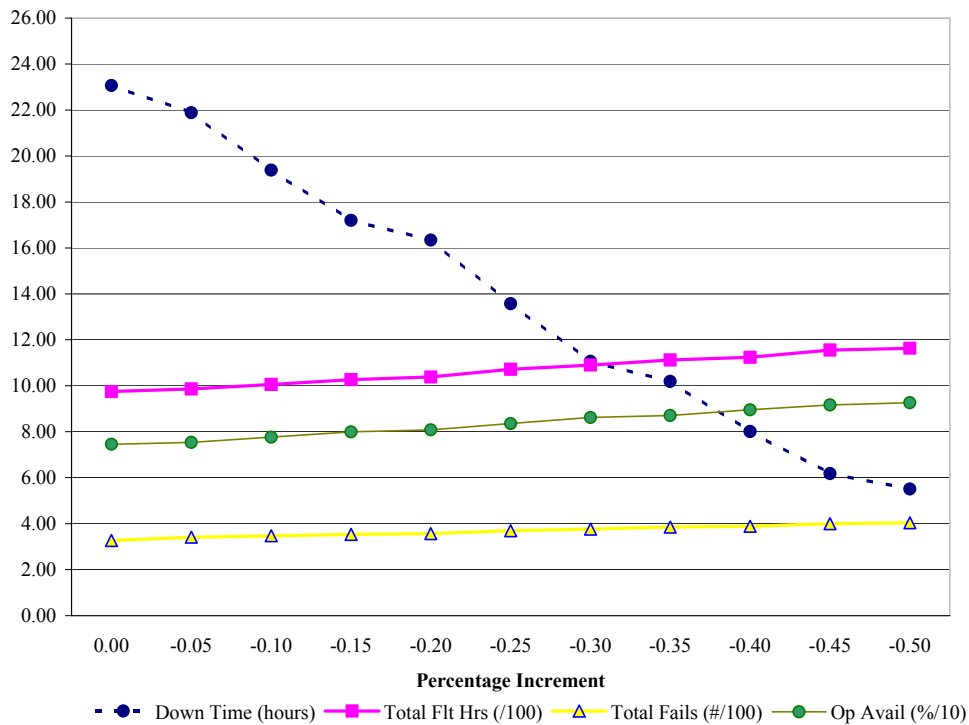
Figure 9.   Chart of Adjustments in Maintenance Times.

4.   Scenario Four: Combined Process and Maintenance Improvements

Having run incremental changes in maintenance times and process delay times, the simulation was modified to increment both simultaneously. The steepest aspect of the curve occurred between 15 to 20 percent indicating the greatest rate of efficiency gained for an optimal range (Figure 10). Operability factors were as follows:

Down time per weapon systems: 9-18.7 hours
Total flight hours per squadron   1054-1113 hours
Total failures per squadron   358-386
Operational Availability: 80.9-88.4 percent
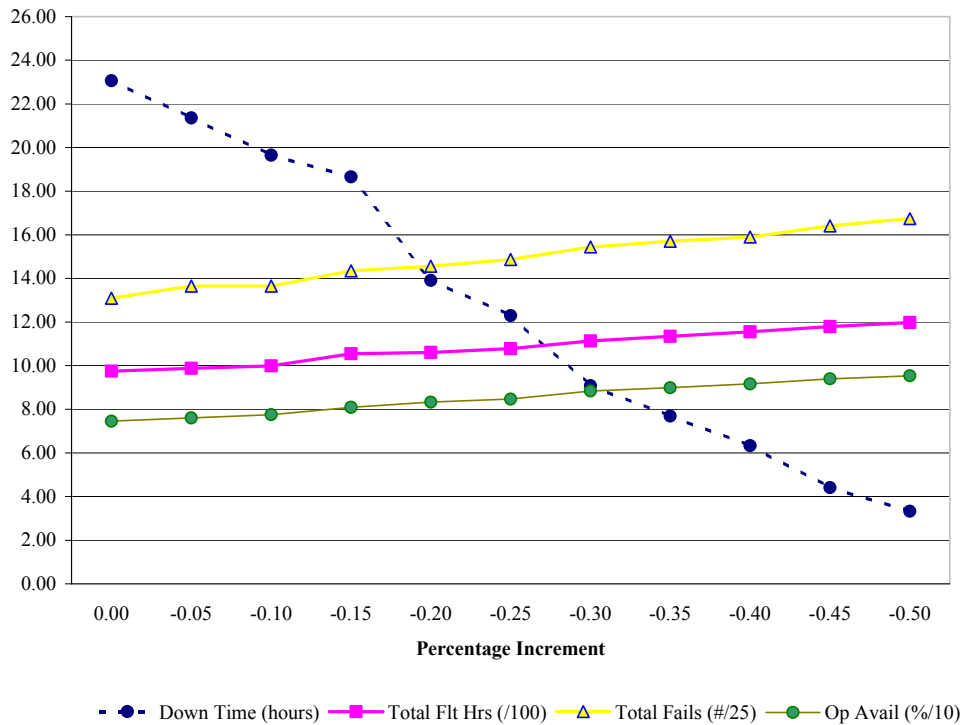
Figure 10. Chart of Combined Adjustments in Maintenance and Process Delay Times.

5. Scenario Five: Increased Reliability

To simulate the impact of changing reliability, the baseline model was modified by increasing the MTBF of the system and top two degraders in 5 percent increments (as discussed in Scenario 1 component failure calculation). Figure 11 shows a plot of down time, flight hours, failures and operational availability with incremental improvements in reliability. The steepest aspect of the curve occurs between 15 and 20 percent indicating the greatest rate of efficiency gained for an optimal range. The related reliability calculation spreadsheets are located in Appendix H.

Down time per weapon systems:	19-22 hours
Total flight hours per squadron	1018-1035 hours
Total failures per squadron	306-311
Operational Availability:	78.3-80.2 percent
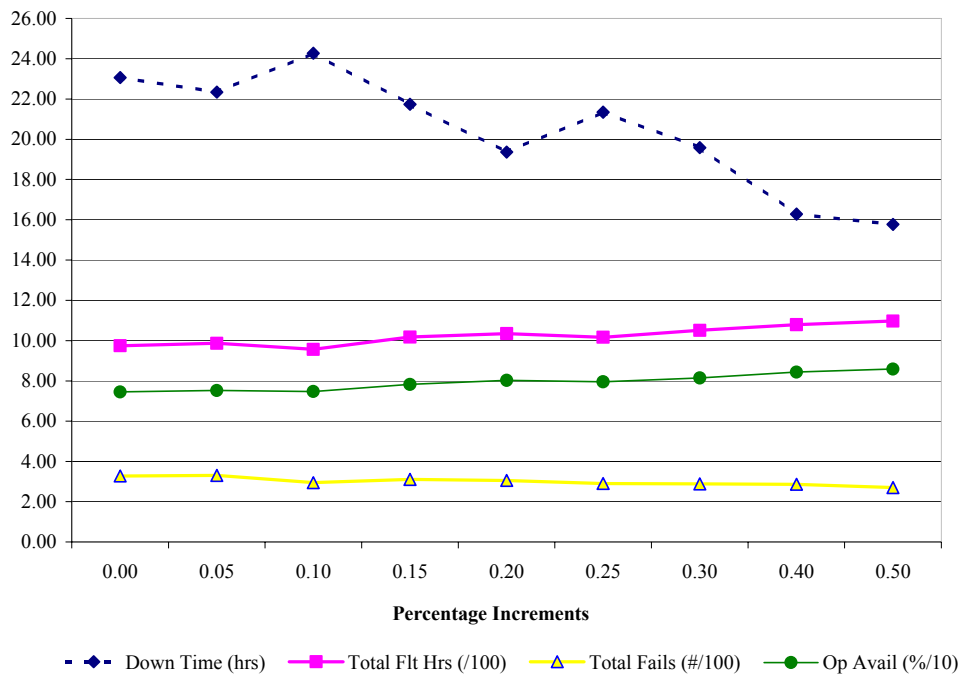
Figure 11. Chart of Adjustments in System Reliability.

Figure 12 provides a graphic comparison of the incremental changes in MTBF and system reliability by contrasting the impact of improving *all components* simultaneously against improving only the *top two degraders* (i.e., Airframes/Flight Controls (WUC 1*) and Radio-Navigation-Weapons Controls (WUC 7*)). The improvements realized by concentrating on the top two degraders yielded nearly the same benefit as the effort to improve all components.
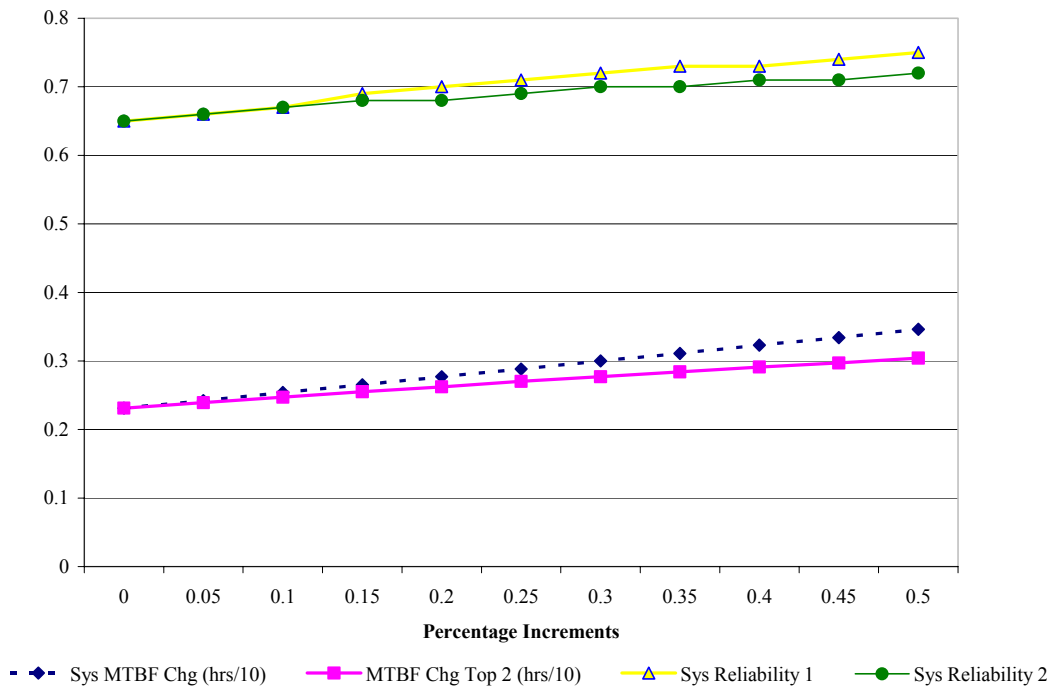
Figure 12.   Comparison of Improvements in System Reliability versus Improvements in Reliability of Top Two Degraders.

F.   ANALYSIS

The advantages of simulation and modeling were noted and observed throughout the analysis. The models were flexible and easy to use as changes in the applications were applied. The results from each model were assessed and the following points are noted:

- Reductions in the process delay time did not have a large impact on operational availability. The benefit of reducing the process delays or eliminating transaction times did not materialize. The curves representing operational availability, total flight hours, and down time stayed relatively flat.

- Reductions in the maintenance process time produced substantial impacts on operational availability, total flight hours, and down time. Maintenance repair time represents a significant part of a components cycle time or turnaround time. By reducing the time required for these activities to repair assets, improvements in operational availability and total flight hours were observed while decreases in down times were measurably noted.

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- Simultaneous reductions in both maintenance and process delay times had a measurable impact on operational availability, total flight hours, and down time. The combination of process and maintenance improvements produced a steep decline in down time. To further analyze the impact, the model was adjusted to reflect a 20 percent improvement and then a specific component was targeted for spare reduction. Improvements of 20 percent enabled a 40 percent reduction in the Airframe/Flight Control sparing while maintaining an average of 78 to 80 percent Ao.

- Increasing the Mean Time Between Failure improved operational availability. The simulation supported pre-determined manual calculations with regard to the increase in availability when the time between failures was increased. Combined with reductions in Mean Active Maintenance time, small improvements in the MTBF had a significant impact on availability. In the first run, the MTBF of each component was improved to determine the impact on system reliability. A second run was then performed in which only the MTBF of the top two degraders were increased. The results of each run were compared to analyze the impact on overall system reliability and overall system MTBF. Though not as significant as the improvements in all components, improving the mean time between failure of the top two degraders produced nearly the same overall system reliability.

- Reductions in maintenance processes impacted availability more than increases in component Mean Time Between Failure. As discussed in the summary in Chapter III, improvements in maintenance practices, which shorten cycle time, had a larger impact on aircraft availability and sparing levels compared to the large the improvements observed in achieving higher component reliabilities.

G.   CONCLUSIONS

The objective of the model simulation was to analyze the impact of the efficiencies that the CROSSBOW framework would provide. Top level aggregated data readily available for download (e.g., VAMOSC, NALDA, DLA) provided guides for designing the decision points and probabilities. Given time to measure the numerous processes involved, the simulation models could be further refined to more accurately refine system behavior.

The simulation evaluated system behavior through a range of 0 to 50 percent improvements. Marginal cost effectiveness was not integrated in this analysis, but must be assessed to determine marginal cost benefits as improvements of 50 percent or greater

are most likely infeasible. While the optimal points differed in all models, generally the optimal target range for improvements was between 10 and 30 percent.

One major note should be highlighted at this point. The readings, up to this point might construe the reader to believe the elimination of manned processes is the major scheme of the CROSSBOW sustainment concepts. The elimination of the man-in-the-loop is not, in itself, the primary goal of the CROSSBOW framework. However, manning is often not a function of system need, but a matter of insurance to ensure system shortcomings are offset. Optimizing the system to eliminate inefficiencies is the primary consideration of CROSSBOW sustainment concepts. From this perspective, the technologies leveraged to implement the CROSSBOW framework can provide efficient performance, error checking, automated data retrieval, and automated identification/diagnostics to eliminate the need to have personnel auditing every transaction. In this way, the CROSSBOW will enable significant cost savings and efficiency.

V. AGING WEAPON SYSTEMS - THE CROSSBOW RESPONSE

A. INTRODUCTION

Aging weapon systems is, arguably, the most problematic issue currently impacting the fleet, aside from modernization which directly affects fleet aging. While there is no specific definition for aging weapon systems, it can be generally described as the degradation of a weapons system caused by age, environment, storage, or operational use that reduces the operability of the system. The impact of aging systems is the reduced performance capabilities of the aged system, increased maintenance requirements, increased O&M, and ultimately, decreased morale of the troops who must maintain the aged systems [Congressional Budget Office, 2001].

This assessment determines that <u>Prognostic Health Monitoring systems (PHM), Condition Based Maintenance (CBM), and Total Asset Visibility are key components of the CROSSBOW concepts that are essential to mitigate the effects of aging systems</u>.

B. BACKGROUND

In a February 2000 Government Accounting Office (GAO) report entitled *Tactical Aircraft: Modernization Plans will not reduce Average Age of Aircraft*, the report concluded that, *Navy Aircraft (and ships) are older than at any point in time in [U.S] history…as equipment gets older, component reliability decreases and depot level maintenance increases* [General Accounting Office, 2001a]. This statement sets the stage for worsening trends in maintenance requirements and reduced mission capable rates as weapon systems wear down with age.

Historically, the Navy attempted to maintain aircraft an average of 7.5 years and retire aircraft at 15 years (ships at 20 years). This target has not been attainable in recent years, with an increased reliance on a single weapon platform without a replacement strategy. For example, the lack of a replacement for the F/A-18 Hornet, as a fighter-attack platform, has forced the Navy to extend the life of this airframe to 2019 [GAO, 2001b]. Coupled, with increased operational commitments, the operability of the F/A-18 system has been severely curtailed [GAO, 2001c]. Aging system experts believe most Navy systems are operating in the wear-out, or mature system aspect of the curve [Edge,

2001]. Results from GAO audits and Navy Inspector General Reports support this assessment [GAO, 2001d].

Without service life extensions, 223 of the Navy's 335 F/A-18s will be out of service by 2014 [GAO, 2001e]. At present, it will take an estimated $878 million to modify and extend the service life of 355 Hornet aircraft to meet future mission needs.

The April 2000 Navy Inspector General report concluded, aging aircraft obsolescence and declining reliability management is being stressed by a *support system that suffers from reduced staffing and maintenance proficiency*. Furthermore, the Navy should *invest in logistics and engineering efforts* to address reliability issues, noting that commercial airlines spend 2 staff years per aircraft for maintenance efforts compared to the Navy's investment of 0.5 staff years per aircraft [GAO, 2000]. What is demonstrated is a clear inability, within the Navy, in building a viable and long-term sustainment framework that supports systems throughout their life cycles.

C.   CURRENT NAVY INITIATIVES

Current Navy efforts at lessening the effects of aging weapon systems include Service Life Adjustment Programs (SLAP) and Service Life Extension Programs (SLEP). SLAP is a two-phase assessment designed to evaluate and assess aircraft life through the teardown and inspection of *fleet-representative* landing gear structures and existing test articles, an analytical assessment of existing and new data, and a structural test of aft fuselage arresting gear structures. The targeted goals for this test and evaluation process are to assess and determine candidates for SLEP.

Following the SLAP evaluation and data collection, a Service Life Extension Program (SLEP) is initiated for selected candidates. The purpose of SLEP is to provide rework and/or inspection based extensions to produce, in the case of the F/A-18, an arrested landing extension to 2700 flight hours, a total landing extension to 14,500 flight hours, extension of flight control surfaces beyond 6,000 flight hours, and to provide new insight into hidden corrosion prone areas.

The rework will implement Engineering Change Proposal (ECP-904) that replaces the center barrel and surrounding structures of the F/A-18 and "zeros" out the

Fleet Life Expectancy (FLE) counter in this section which allows the aircraft to be flown an additional 6,000 hours (see Figure 13). The total cost of ECP-904 is $878 million and is currently scheduled to begin fleet implementation in December 2001.
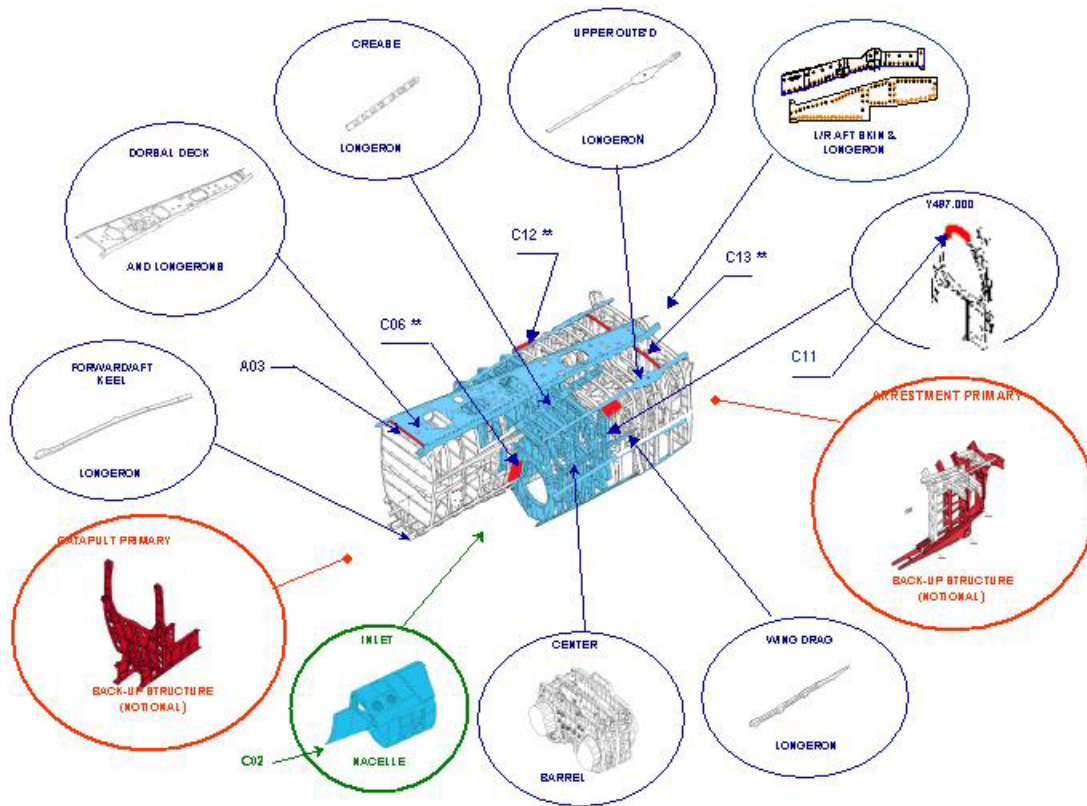
Figure 13.   ECP–904 Center Barrel and Surrounding Structure Replacement.
(From NASNI NADEP)

Although these initiatives are intended to provide extended life for current assets, these methods are limited in their ability to assess aging problems *as they occur*. These rework methodologies assume systems incur aging problems with the increased age of the system, when in fact systems experience aging characteristics soon after acquisition. Additionally, these methodologies do not factor in the increased operational commitments performed by the weapon systems.

The aging issues at hand include the areas of structural fatigue, hydraulics corrosion, operation/flight controls degradation, maintenance contamination (inadvertent damage due to maintenance), wire cracking and fatigue, and depot level maintenance deferral. Easily inferred, aging weapon systems creates increased requirements for manpower, resources, and specialized training to counteract the deteriorating impacts to the aging systems.

D.   CROSSBOW FRAMEWORK APPLIED

The CROSSBOW sustainment and maintenance concepts seeks to mitigate and deter age-related issues through real time data collection with *up to the minute* Fleet Life Expectancy (FLE) tracking, and improvements in forecasting and trend analysis. With comprehensive system visibility and near real-time weapon system status, aging degradations can be tracked, assessed for impact, and repaired *when required* rather than reacted to *when planned* with current repair methodologies.

Aging symptoms, as a whole (e.g., structural fatigue, hydraulics corrosion, operation/flight controls degradation), are accurately diagnosed by the prognostic and diagnostic systems derived by the PHM system (Autonomic Maintenance Module) as well as detected by the Condition Based Maintenance multi-sensor systems. Tracked on an asset-by-asset basis by the Autonomic Logistics Module for component degradation data, this information is automatically cached within the Total Asset Visibility database and instantly relayed to all major stakeholders for analysis and planning assisted by the Decision Support System (C4I).

Maintenance contamination caused by continuous handling of systems and access panels, coupled with poorly trained technicians, represent another aging determinant. Maintenance contamination is lessened with highlighted training requirements identified through shared data between the Training module, TAV database, and the Autonomic Maintenance module. Focused schoolhouse training, online/interactive training for inexperienced technicians, and refresher training for seasoned technicians ensure proper instruction when and where it is needed. Vendor/Contractor visibility of problem areas would lead to the design of easily removed and replaced modular systems and panels, designed with human factors in mind, significantly lessening the deteriorating aspects of

system and component handling. Additionally, CBM and PHM systems would accurately measure system operability, precluding the need to remove panels or handle systems needlessly.

Widespread Wire Damage (WWD) could be detected early on through PHM identification of wire insulation deterioration, either caused by chafing or polymer chain scission [Eaton, n.d.]. A difference in signal strength would be noted by trend analysis tools and compared against a known baseline for significance. Comparative and qualitative differences would be relayed to the Autonomic Maintenance Module for scheduling, inspection, and repair actions if necessary. The Vendor/Contractor module would also receive needed data to identify potential causes of WWD, initiate necessary repair actions, and prompt engineering changes to preclude future damage. CBM would inhibit potential maintenance deterioration caused by human factors.

Depot level maintenance deferral is believed to produce considerable cost savings with the delaying of weapon systems overhauls until absolutely needed. This premise is based upon repair of systems only as they reach maturity. The flaw in this premise is the determination of maturity. Current methodologies are unable to ascertain component aging degradation within its current life cycle. Questionably, depot engineers believe they can predict up to 78 percent of Fleet Life Expectancy (FLE) remaining in an aircraft. Through implementation of a robust data collection method (TAV database) coupled with specialized forecasting tools, FLE could be predicted with greater accuracy [Brown, 2000].

The aging of systems cannot by prevented. However, the accurate and timely detection of improper operating parameters allow for key repair action before significant deterioration or catastrophic component failure occurs. Made possible by PHM and improved forecasting and trend analysis tools, the CROSSBOW Autonomic Maintenance Module reacts quickly and decisively in the repair of the system. The Autonomic Logistics Module tracks the component data for failure trends. The TAV database collects the data while the Intelligent Agents search the data for prevalent aging system symptoms. The Vendor/Contractor Module provides the OEM accurate information to repair or re-engineer the aging problem area. The Training Module provides an adequate

assessment of fleet maintenance needs to focus the training on critical areas. The C4I Module, aided by the Decision Support System, is able to present an accurate status of weapon systems as they experience aging factors. Brought together, the CROSSBOW sustainment framework produces a robust system analysis and decision centered approach to aging weapon systems currently not available to the fleet (see Figure 14).

Aging Systems Traits

CROSSBOW Logistics	Depot Level Maintenance Deferral	Maintenance Contamination	Struct. fatigue, Hydraulics Corrosion, Operational flight controls degradation	Widespread Wire Damage
Prognostic Health and Monitoring System		X	X	X
Autonomic Maintenance Module		X	X	X
Autonomic Logistics Module			X	
TAV Database	X	X	X	
Condition Based Maintenance	X	X	X	
C4I DSS			X	
Training		X		
Modular Systems		X		
Trend Analysis - Forecasting Tools	X			X
Vendor-Contractor			X	X

Figure 14.   CROSSBOW Sustainment Applications on Aging Systems.

E.   CONCLUSIONS

While considerable effort continues in the reduction of aging system's effects as they occur, additional effort is needed in timely data collection and pre-emptive maintenance to allay the effects of aging systems. Contrary to logic, depot level maintenance continues to be deferred and system designs are lacking in internally diagnosing technologies.

Increased funding for aging system research, manpower, and spare procurements will aid to some extent. However, according to the February 2001 GAO report, Navy studies differed on the rate of cost increases and the types of support costs impacted by age and at least one other study indicates consistent and reliable data were not available for long enough periods to demonstrate the impacts of age. This report infers the data the Navy is collecting (in 3M systems) is not meeting the minimum requirements to justify Congressional budget movement towards additional funding for appropriations for this funding intensive problem.

The solution lies in an integrated proactive, strategic maintenance management program enabled by technologies demonstrated within the CROSSBOW framework. As weapon systems age and budgets continue to become more constrained, a realistic assessment of system operability is not only desirable, but also essential. The CROSSBOW sustainment concepts systematically identify degradation and problems as they occur, and derive solutions as they are needed. Able to access current data, extrapolate trends, and offer evaluation, the CROSSBOW sustainment concepts presents a potential resolution to a significant logistics problem.

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VI. NAVY CULTURE

A. INTRODUCTION

Potentially, the greatest challenge faced in implementing logistics and maintenance innovations, such as the CROSSBOW logistics concept, is Navy culture. Despite the magnitude of life cycle support costs, one F/A-18 costs $4 million per year (Naval Aviation Logistics Data Analysis, 2000b), the emphasis of cost remains myopically with the initial acquisition purchase price. Given little voice during the design of the weapon system, logisticians face unrealistic system reliability estimates which drives the increased need for spares, decreases readiness, and increases O&M costs for sustaining the system [Eaton, n.d.].

Faced with supporting maintenance intensive weapon systems, technicians and logisticians are initiated into a culture of learning to do *more with less* and performing the mission at all cost. Failure in the successful performance of a mission is deemed an unacceptable outcome. Rather than fail, technicians (and commands) resort to shortcuts, work-arounds, and misrepresentations of readiness to feign the appearance of mission readiness. This dangerous acceptance of fabricating mission readiness permeates from the lowest technical shop up to the Joint Chiefs of Staff. In response to Joint Chiefs of Staff failure to accurately report the military readiness to the Senate Armed Services Committee, Senator McCain said to the Chiefs, *the fact [is] that you were not candid to this member in the problems and challenges that we faced* [New York Times, 1998].

This assessment addresses some of the more prevalent cultural issues within the Navy that must be addressed in order to effect positive change in logistics and maintenance.

B. BACKGROUND

Culture is best defined as the set of assumptions, beliefs, values, and norms that are shared among members [Newstrom et. al, 1993]. The culture is integral to an organization's success as it defines the mission, provides stability and continuity within the organization, and provides the context for events that would otherwise seem

confusing or misleading. Culture permeates an organization and is strongly influenced by top management.

Navy logistics and maintenance practices have remained largely unchanged for the past thirty years. Arguably, so has the logistics and maintenance culture - despite the fall of the U.S.S.R. and a dramatic downsizing of Naval forces from 600 ships to 317 [Chief of Naval Information, 2001]. This culture has struggled to define new missions, assess shifting priorities, and deal with increasing scrutiny from Congressional stakeholders wanting the most bang for their appropriated bucks. However, with little change to the inefficiently massive infrastructure that provides support, an ever-increasing operational tempo, and the establishment of new asymmetric threats that pressure forces to respond in new ways - the inefficient aspects of the Navy culture are greatly exposed which undermine readiness.

Some of the more prevalent sub-optimizing aspects of Navy culture include:

1. The lack of spares, exacerbated by progressive weapon system aging, impels technicians to cannibalize for replacement parts to repair weapon systems. As quoted from the September 2001 Navy Times, "At VF-101, the fleet replacement squadron for F-14 Tomcats based at Naval Air Station Oceana, VA, the aviators are feeling the crunch of old airplanes and a shortage in spare parts. "We have the money to fly the jets, but we don't have the parts to repair the jets," stated one of the instructor pilots [Navy Times, 2001]." The same report cited a July 2001 GAO report which found that up to 17 percent of Prowlers and Tomcats were not mission capable due to spare-parts shortages. The shortages were due to greater demands than anticipated and delays in awarding contracts for parts delivery from 1993 to 2000. This lack of spares, coupled with the weapon system aging problem, translates into undesired maintenance practices such as cannibalization - or the removal of parts from one aircraft to repair another. This type of practice typically doubles the amount of work necessary to repair the aircraft and decreases overall reliability.

2. Navy culture maintains the principle of performance of the mission at all costs. This credo often pushes the boundaries of risk whereby jury-rigging, cannibalizations, and fast fixes become commonly acceptable in light of reduced spares availability and unreliable weapon systems. Coupled with a *shoot the messenger* approach to negative mission performance and readiness reporting, few Sailors are willing to countermand this unsaid edict of performance.

3. <u>Critical influxes of acquisition funding are routinely diverted to offset operational shortfalls.</u> The number of procurements of new aircraft has commonly been sacrificed to compensate for the sparing and support shortfalls. The fiscal 2002 budget proposal was projected to buy 88 new airplanes. The goal for buying new major equipment (i.e., airplanes), or recapitalization, was between 180 and 210 to offset attrition rates. From 1998 to 2001, the Navy transferred 7.5 billion dollars from recapitalization accounts to readiness accounts to offset degrading readiness indicators. Shifting funds from modernization to readiness accounts exacerbates the problem.

4. <u>Apprehension regarding advanced development through automation in ship operations.</u> Optimization of DD-21 manning, from 350 Sailors to 95, has met with great resistance. A commercial consultant working to develop the optimized manning plan noted that the Navy's culture did not favor unmanned spaces and consoles. The consultant's view that the Navy tended to be very wary of automated controls was lent support by a Midshipman briefing at the Naval Academy where nearly fifty percent of the questions referred to fear of losing the redundancy of manual backups to that of automated systems proposed for DD-21. The Midshipman also expressed concern regarding manning for damage control and what controls were in place to ensure adequate protection in spite of minimal crew sizes.

    The initial design of the Oliver Hazard Perry - Class Frigate provided an engine control room with automated systems. In spite of the controls, the Navy manned the control rooms with watch standers that monitored the gauges during their entire watch.

5. Other cultural issues include:

    - No incentives are provided to develop and unilaterally integrate weapon systems to optimize life cycle support. On the contrary, Program Managers (PMs), system engineers, and OEMs strive for system performance while largely ignoring the premise of establishing commonality between weapon systems. Integrated open systems architectures that enable true integrated logistics and maintenance support are seldom considered early in the development phase of any weapon system.

    - During initial acquisition, reliability estimates provided by the OEM engineers are critical in establishing sparing levels and technical support criteria. Experience has shown the system reliability estimates to be dramatically incorrect. The null hypothesis of having the OEM prove reliability estimates, as accurate computations, is seldom enforced [Raia, 2001]. What results is the development of a sustainment package based upon

incorrect reliability data, often producing sparing shortages, test equipment shortages, and decreased readiness.

- Navy support commands operate under conflicting incentives that reward individual organization performance vice weapon system support. Navy item managers base their performance on misleading measurement criteria that provides deceiving operational support determinations. Measurement criteria such as Supply Material Availability (SMA), Number of Backorders, and Average Customer Wait Time (ACWT), or Supply Response Time (SRT), have little to do with operational readiness and are self serving for the managers within the support command [Kang, 1997].

- The reward system for operational Commanding Officers is not judiciously coupled to the proficient use of budgets or efficient use of weapon systems. Reprimands are levied, by higher commands, if all operational funding is not expended by the end of the fiscal year. Promotions are coupled to the number of aircraft hours flown, number of ship steaming hours performed, and maximization of fuel allocation/usage. Little regard is given to the operational stress placed on the weapon systems and personnel as they are pushed ever harder to outperform the prior COs accomplishment.

C. THE NEED FOR CHANGE

The increasing cost of weapon systems (acquisitions) dictates the need to intelligently maintain these systems by reducing the cost of the support infrastructure while increasing operational availability - as well as not trading off logistics supportability features for more quantity or performance. This will only be accomplished with a significant paradigm shift in current acquisition, logistics, and maintenance methodologies. This cannot be accomplished without support from top leadership - without a committed and lasting champion.

Firm program readiness targets must be established that re-acclimate the acquisition stakeholders to balancing the variables between acquisition costs, system reliability, and system sustainability. This paradigm shift will require the use of new models, such as the Brandenburger-Nalebuff model, that facilitates these new and often contradicting requirements [Brandenburger-Nalebuff, 1996].

Rewards and incentives must be realigned to congruently direct all resources, manpower, and intellectual capital in the common pursuit of system optimization. Singular and self-serving incentives must be discouraged to signal, throughout the Navy logistics culture, that new and more prominent priorities are now emplaced.

The suggestion of a new logistics professional should be addressed. System designs are becoming increasingly complex requiring better-trained professionals. Most readings rationally discussed comprehensive use of logistics engineers to offset the increasing complexity [Moore, n.d]. One prominent expert recommends the implementation of a two-tier system for logistics skill sets. The first tier would encapsulate acquisition logisticians with engineering degrees (e.g., mechanical, electrical) while the second tier would be made up of sustainment logisticians with general business degrees (e.g., finance, acquisition). The acquisition logisticians would be better suited in the complex and engineering-intensive acquisition environment while the sustainment logistician would be best trained in the business aspects of Navy supply support. Tightly aligned system goals would ensure mutuality between the parallel logisticians' efforts to preclude professional enmity [Eaton, n.d.].

D. CONCLUSION

Any attempt to fundamentally change the current logistics and maintenance methodologies will not be successful without addressing the issues of culture. Issues such as incentives/reward system, current support paradigms, and establishing trust will require intelligent shaping to ensure a sustainment system, such as the CROSSBOW sustainment concepts, is properly aligned with the culture. CROSSBOW's integrated and automated monitoring and reporting systems will help alleviate apprehension, but will still require unequivocal support from Navy culture.

Proactive planning, courage, active involvement on all levels of support, and a clear vision are the essential impetus to begin the cultural change. The establishment of empowered logisticians and maintenance officers at critical levels of acquisition, sustainment planning, and life cycle cost analysis, will initiate a change of perspective in weapon system support. The alignment of incentives with increasing system operability will establish congruence between resource providers and mission needs. Rewarding

Commanding Officers for mission performance instead of successful expenditure of resources will exert critical resources only as needed - reducing the operational stress placed on weapon systems.

Most importantly, a climate of efficiency, increased innovation, and candor will eventually characterize the Navy support structure. Readers of this chapter have reason to be skeptical. Years of cultural inertia, Department of Defense bureaucracy, shifting political agendas, and stalwart military gate-keepers suggest significant change is not only impractical, but virtually impossible given the current Navy mindset. However, nothing short of significant change will remedy the shortcomings of the current acquisition and sustainment methodologies.

Technologies and innovative methodologies exist *today* that, if successfully integrated into a coherent and formulated manner, will provide substantial returns in efficiency translating into increased system operability and LCC avoidance. These innovations are moot without top-level support and a Navy culture that embraces logistic supportability change rather than relegating it to its current level of unimportance.

VII. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the general conclusions and recommendations that follow from the thesis.

Conclusion 1. The current logistics and maintenance environment is manpower intensive, inadequately supported with Jurassic data systems, sustained within an inefficient infrastructure, and inflexible to emerging operational requirements.

Recommendation 1. The Navy should invest in the research and technology development areas listed in the Roadmap (Appendix C). The effort should be in designing and integrating weapon systems with logistics and maintenance as a design criteria rather than a post design provision.

Conclusion 2. Emerging technologies, as presented in Appendix C, are critical for reducing manpower requirements, enhancing training, increasing asset visibility, reducing maintenance requirements, decreasing repair cycle time, and increasing operational availability - thereby translating into the sustainment of an effective and dynamic weapon system. The CROSSBOW sustainment concept provides a general example of an integrated framework with new technologies and methodologies that are obtainable now.

Recommendation 2. The Navy should assume the null hypothesis that *currently used* technologies and methodologies will not adequately support the accelerated battlefield tempo and autonomous operations expected in the year 2020. Given this premise, all effort should be expended *now* to conduct analysis, within a Systems Architecture/Engineering methodology, to adapt and integrate new technologies and methodologies to meet the requirements of the future Naval force.

Conclusion 3. Life Cycle Cost Analysis indicated significant cost savings were possible with the acquisition and fielding of the Unmanned Combat Air Vehicle.

Comparative analysis supported this assessment whereby the reduced sustainment cost for a UCAV could be directly translated into the purchase and utilization of more unmanned aircraft. Additionally, the UCAV development and sustainment costs were a

fraction of current F/A-18C aircraft costs. Removal of the human from the cockpit realized a training cost reduction of 99.1 percent.

Recommendation 3. The increasing use of unmanned vehicles provides indication of the utility of these systems. The Navy should not only establish a UCAV implementation plan, but a robust robotics implementation plan to eventually fully integrate these systems into Naval operations.

Conclusion 4. The UCAV's reduced requirement for performing flight for training reduced repair requirements throughout the repair pipeline - lending to consideration of reducing or eliminating intermediate level repair.

Recommendation 4. The reduction in flight hours required to maintain proficiency is dramatically reduced with the simulation training provided with the UCAV system. Reduced flight hours translated into less maintenance actions that inferred a reduced I-level or a direct O-level to Original Equipment Manufacturer (OEM) logistics pipeline might be undertaken. With the implementation of a direct O-level to OEM methodology, the idea of a truly centralized Inventory Control Point (ICP) for the UCAV support infrastructure could be entertained. This concept would require a robust interface between commercial carriers and military transport as well as improvements in the interface between the current Navy ATAC and DOD transportation system.

Conclusion 5. Using Arena 5.0 Simulation tools, the analysis determined that an increase in efficiencies between 10 and 30 percent, imposed upon a baseline model, produced an optimal range of Operational Availability of 77 to 86 percent. The optimal range serves as a target for the implementation of new technologies and methodologies.

Recommendation 5. The increased capabilities of simulation software tools provide tremendous flexibility and strength in assessing system characteristics and behavior. The Navy should invest in a comprehensive simulation and modeling program for all major systems.

Conclusion 6. Despite the destructive impacts of Aging Weapon Systems, the utilization of Prognostic Health Monitoring systems (PHM), Condition Based Maintenance (CBM), and Total Asset Visibility tools help to mitigate the effects.

Recommendation 6. The Navy should invest in a proactive and strategic maintenance management program enabled by technologies demonstrated within the CROSSBOW framework. As weapon systems age and budgets continue to become more constrained, a realistic assessment of system operability is not only desirable but also essential. The CROSSBOW sustainment concept systematically identifies problems as they occur, and derives solutions, as they are needed. Able to take current data, extrapolate trends, and offer evaluation, the CROSSBOW logistics concept presents a potential resolution to a significant maintenance and readiness problem.

Conclusion 7. Navy culture serves as a major roadblock in the implementation of new systems. These cultural issues must be addressed in order to effect positive change in logistics and maintenance methodologies.

Recommendation 7. Recognizing the fundamental need for change, a number of cultural issues must be addressed that include:

- The need for top-level support to create a vision and a politically powerful champion

- Established readiness targets to re-acclimate acquisition stakeholders

- Re-aligning rewards and incentives for congruence of mission needs with mission resources

- The potential establishment of a new type of logistics officer to address the ever increasing complexities of new weapon systems

These problems are not all inclusive of the cultural issues faced, but largely represent the dilemmas that require concerted effort to impose necessary change.

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APPENDIX A. SEA ARCHER MNS – VERSION 1

SEA ARCHER MISSION NEED STATEMENT FOR CROSSBOW Version 1

SEI 2

Bauer	**Marvel**
Brown	**Muldoon**
Carroll	**Ng**
Chew	**Quast**
Darling	**Raia**
Edge	**Ray**
Foo	**Schuette**
Ho	**Siew**
Lantier	**Sng**
Lim	**Yeo**

A. **SEA ARCHER MISSION NEED STATEMENT FOR CROSSBOW (VERSION 1)**

1. **General Description of Operational Capability**

a. *Mission Area*

(1) The U.S. National Security Strategy has shifted from a focus on a global threat to a focus on regional challenges and interests in the littoral. While the prospect of global war has receded, we are entering a period of enormous uncertainty in regions critical to our national interests. Our forces can help to shape the future in ways favorable to our interests by underpinning our alliances, precluding threats, and helping to preserve the strategic position we won with the end of the Cold War. Naval Forces will be full participants in the principal elements of this strategy--strategic deterrence and defense, forward presence, crisis response, and reconstitution. The Naval White Papers "Forward From the Sea" and Operational Maneuver From the Sea (OMFFTS) provide direction to the U.S. Navy (USN) and the U.S. Marine Corps (USMC) concerning the challenges of the post-Cold War world and shift the operational focus of naval forces from the open ocean to the world's littorals. The concept of Littoral Warfare emphasizes the capability of naval forces as a forward deployed crisis response force to deter conflict in the littorals, and to prevent escalation and restore stability where deterrence has failed. These Naval forces will meet far greater threats in numbers, quality and intelligence of weapons. As simultaneous coordinated attacks come with larger number of all types of weapons (from subsurface, surface, air and space), any Naval force will have far less time to plan and carry out defensive and offensive operations. This view of a combat operation in the time frame of 2020 will require a mix of all types of Airborne missions both manned and unmanned operating from the Sea Archer class ship. For planning purposes, the CROSSBOW equipped task force will embark from San Diego for the South China Sea in September of 2021. All new Missions, Technologies, Equipment, and Operations Strategies must have Follow on Operational Test and Evaluation completed by the Summer of 2021.

(2) The state of the world in Asia in 2020 is defined by the final report of the SEI 1 class and the two books by Michael Pillsbury on China. With a far greater emphasis on joint and combined operations, the Navy, Marine Corps, Army and Air

Force will provide unique capabilities of indispensable value in meeting our future security challenges especially in the littorals. Ready, relevant, and capable American Naval Expeditionary Forces provide: a powerful yet unobtrusive presence, strategic deterrence, control of the seas, extended and continuous on-scene crisis response, precise power projection from the sea, and sea lift if larger scale war-fighting scenarios emerge. These maritime capabilities are particularly well tailored for the forward presence and crisis response missions articulated in the emerging National Security Strategy. The requirement for the capability to deploy, transport, and project landing forces in sufficient strength and capacity for the conduct of up through Marine Expeditionary Force (MEF) level amphibious operations without nearby land bases for support has been identified in the Marine Corps Master Plan (MCMP) 1996-2006.

(3) Our ability to command the seas in areas where we anticipate future operations allows us to resize our naval forces and to concentrate on those capabilities required in the complex operating environment of the littoral or coastlines of the earth. Naval Expeditionary Forces maneuver from the sea using their dominance of littoral areas to mass forces rapidly and generate high intensity, precise offensive firepower at the time and location of their choosing, under any weather conditions, day or night. Operating in the Littorals requires mobility, flexibility and technology to mass strength against weakness in a timely manner.

(4) Our National Security Strategy Requires a Strong Forcible Entry Capability into the littoral areas and adjacent land. As discussed in detail in the Department of the Navy's Concept of "From the Sea", America's interests will continue to dictate the necessity to influence events on the other side of our protective oceans. While even the viability of political reinforcement, by uncontested[1] forward-presence forces, requires a credible forcible entry capability, the requirement to respond against an invader or international outlaw requires the unquestionable ability to place power in the littorals and ashore. In 2020 with few adjacent land bases in the world, the requisite sustainable, forcible entry capability can only come from the sea. In this time frame, allied forces will be required to enter areas defended by integrated systems of modern space, air, sea, and ground weapons. While some defenses will consist of relatively

immobile forces and fixed positions, others will include mobile, combined-arms units-backed by space weapons, naval and air craft (manned and unmanned) and employing the newest unmanned vehicles, missiles and mines against our planes, ships, and landing forces. Design of operations and forces to defeat these opponents must accommodate our societal intolerance of attrition and demands for victory.

(5) "Forward From the SEA"(FFFTS) is a concept for projecting naval power in the littorals and ashore in support of a strategic objective. Essentially, FFTS is the application of maneuver warfare principles to the maritime portion of a theater campaign, capitalizing on the ever-expanding capabilities of modern naval airborne forces (manned and unmanned) to project power in an increasingly sophisticated and lethal environment. Operations are designed to break the cohesion and integration of enemy defenses while avoiding attrition oriented attacks. Emphasis will be placed on speed, mobility, deception, surprise, and other measures of battlefield preparation that confuse or create uncertainty and delay in the enemy's actions. Our ultimate desire is to destroy his will to fight or carry out actions contrary to the interests of the United States.

(6) FFTS is a single, seamless operation extending from homeports to secure sea bases across the littoral to dominate a critical enemy center of gravity. The FFTS concept requires a single force that can change its character with its environment but always operate with a single objective. FFTS brings all facets of sea power to bear; it replaces our recent history of separately controlled movement, supporting operations, landings, and maneuver ashore. The next generation of technology provides our opportunity to close the battlefield mobility gap between space assets, airborne operations, ship firepower and on shore forces, to link maneuver in ships, space assets, airborne operations with maneuver ashore.

(7) Increased operational speed will be the sum of more rapid decisions of command, faster methods of control, quicker execution, higher speed of sea borne systems, and blurring distinction between maneuver at sea and maneuver in the littorals. Relative operational speed (the difference between our speed and that of the enemy) will increase as enemy operations are degraded by simultaneous surprise, deception, strikes, fires, and special / information operations. The moment of achieving superior operational

tempo will be reached when the frequency of our operations do not allow our opponent to respond effectively or maintain cohesion of his forces.

(8) While strike and special operations are complementary forms of sea power projection, new technologies, equipment, and tactics will be required to allow the navy after next to gain superiority in the littorals. The conduct of a littoral operation encompasses almost all types of ships, aircraft, weapons, and landing forces of the U.S. Navy and Marine Corps in a collaborative military effort. The salient requirement of the littoral operation is the necessity of rapidly building up combat power from an initial level of zero to full coordinated striking power to gain success and maintain objectives.

(9) Future naval forces will be structured and equipped to project combat power in the littorals to seize control of the crisis arena for follow-on joint operations. Power projection requires air, space and water mobility, speed, firepower, and a versatile mix of survivable vehicles that enable launch in nearly all weather from a sea base of versatile ships. The force provides standoff (Battle space) for the Naval Task Force to enable the effective employment of active/passive defense systems against enemy air and surface-fired weapons, avoids the major sea mine threat and avoids attrition. The Battle space will be very complex around the task force with large numbers of enemy and friendly manned and unmanned vehicles in the air.

b.   Type of System Proposed

Title 10, U.S. Code, directs the Navy to develop equipment used for maritime operations. This MNS addresses the operational capabilities and design considerations for Sea Archer, the centerpiece of the CROSSBOW Battle Group.

c.   Operational Concept

(1) As part of the Navy after Next initiative, the Navy plans to introduce a new Battle Group concept called CROSSBOW (Figure 1), designed from the bottom up for littoral operation. This new force should operate primarily in the littoral environment as a complement to the CV Battle Group (CVBG) and yet be capable of operations independent of the CVBG during certain Military Operations Other Than War (MOOTW) and low intensity conflicts. CROSSBOW should provide additional assets to assist in the penetration of the littorals to suppress/soften enemy Integrated Air Defenses

(IAD) and area denial capability to provided CVBG access. When low intensity or MOOTW activities lead to escalation, CROSSBOW provides a credible force to harass and suppress enemy forces, while awaiting CVBG arrival. CROSSBOW forces may consist of squadrons of Sea Archers, small expeditionary aircraft carriers (approximately 6-8 –actual number yet to be determined through analysis) operating in concert with up to 20 Sea Lance, which are small, low cost, high-speed combatants capable of deploying the Expeditionary Warfare Grid (EWG) and providing offensive and defensive missile fires. By using distributed sea based air assets, CROSSBOW should be capable of supporting continuous, rather than pulsed, air operations. The Sea Archer air wing, CV air wing, Sea Lance, and other escorts operating in the area of action will provide force protection and offensive firepower. One or more Sea Quivers, which are high-speed support ships, should provide logistic and maintenance support for the CROSSBOW Battle Group. The smallest CROSSBOW operational element is envisioned to consist of two Sea Archers and four Sea Lances capable of operating independently.

(2) The Sea Archer air wing should consist manned and Unmanned Air Vehicles (UAVs). For air vehicle quantities and other planning factors see Table 1. Flight deck design should focus on automation. High-speed launch and recovery operations should take place from an unmanned flight deck. The Sea Archer air wing provides the eyes and ears of the CROSSBOW force. Targeting and reconnaissance information should be provided via appropriate data links to Sea Lance and armed airborne units for a coordinated engagement. A significant number of airborne missions must be launched from the Sea Archer to support a CROSSBOW Battle Group operating in the littoral environment. No single airborne platform is expected to accomplish all of the required missions and all missions do not need to launch from a single Sea Archer. It is recognized that some missions may require the simultaneous operation of more than one of any given airborne platform type. Airborne capabilities are detailed in the CROSSBOW Airborne Systems MNS and highlighted in Figure 2.

(3) Sea Archer may have the ability to act as a "Lillie pad" (recover, fuel, & launch) for AV-8s, VTOL JSFs, and helicopters under 30K lbs max gross weight. Sea Archer is not intended to deploy without an air wing aboard.

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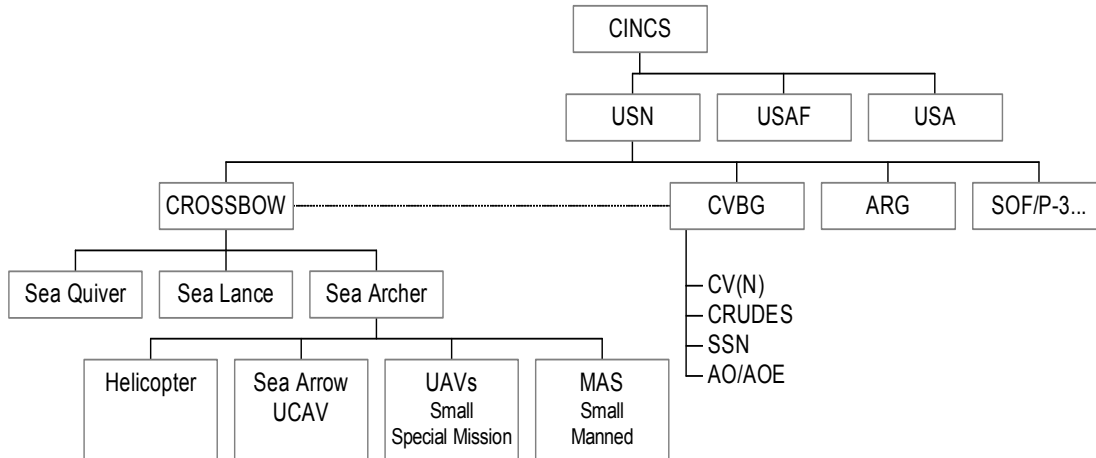
Figure 1.   Crossbow: a View From the Top.

Figure 2
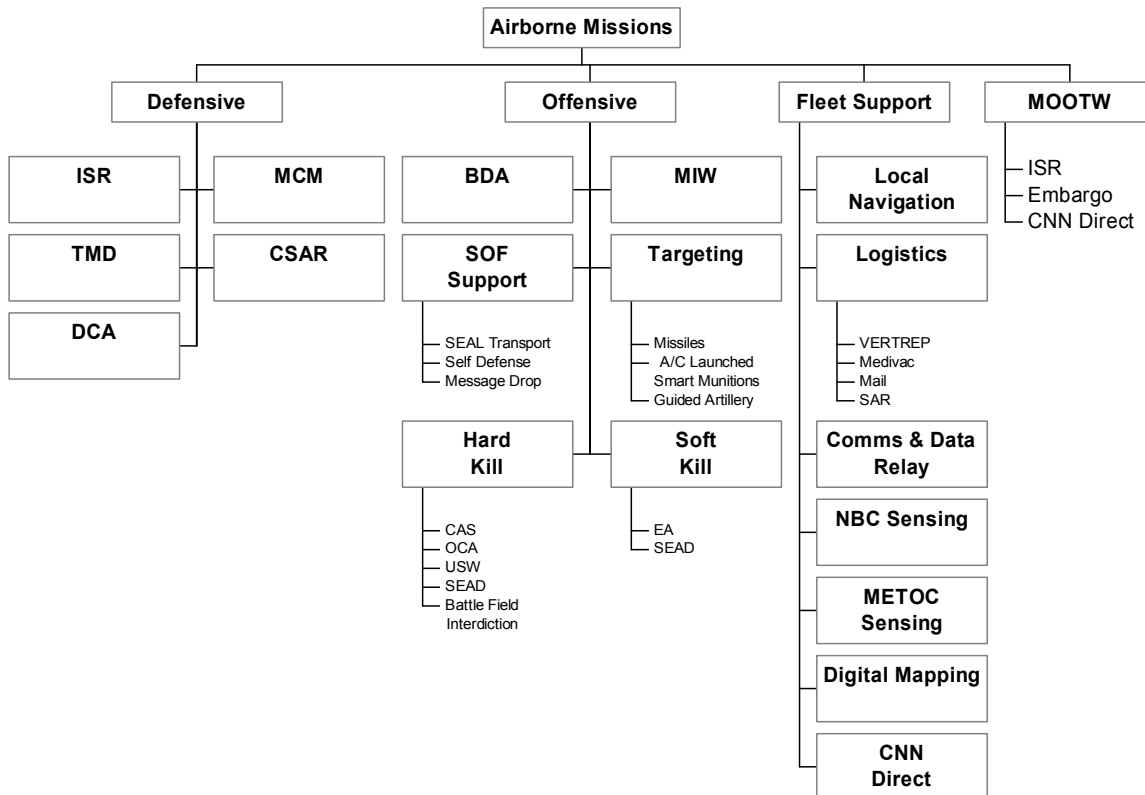
Air Vehicle Type	No.	Unit Weight (lbs)	Total – Type Weight (lbs)	Sortie* Rate Per Day	Sortie* Rate (Surge) Per Day	Spot Factor* @ Launch	Stored	Aircrew w/Seat Factor	Total Aircrew	Remarks
Helicopter • Utility or • Attack	2 or 3	23K or 15K	46K or 45K	8 12	12 18			2.5 2	5 6	One or the other type may deploy on any given Sea Archer, so CROSSBOW has a mix (H-60 / AH-1Z..)
UCAV • Sea Arrow	8	15K	120K	28	42			1.5	12	As AA team refines the design these #s will be updated
UAVs • ???	10	3.5K	35K	32	50			.25	3	Placeholder for the unknown small UAVs we anticipate including.
MAS Aircraft • ???	3	15K	45K	8	12			1.5	5	Placeholder – several candidates are under 10K – MAS=Maneuver Air Support
TOTAL	**23**		**246K**	**76**	**116**				**25**	
	24		**245K**	**80**	**120**				**26**	

* These are very preliminary – campaign analysis mini-studies & further research on platforms will help to refine the numbers. Additionally, launch intervals and turn-around times need to be specified.

Table 1.   Planning Factors.

d.   *Support Concept*

(1) Historically, requirements definition for system logistics and maintenance support has been left until far too late in the acquisition cycle. Early and rigorous logistics analysis is needed to prevent excessive Operations and Support (O&S) costs. Weapon system capability rates have been in a steady decline due to reduced budgets, system operation beyond intended design life, inaccurate failure rate projections, and closed/proprietary architectures. Sea Archer design must facilitate rapid and cost-controlled incorporation of new technologies as they become available.

(2) Supportability, maintainability, and reliability should be designed into Sea Archer. The ship should have an embedded logistics/maintenance system to improve readiness throughout its lifecycle. Significant O&S cost reductions may be realized through decreased repairs, spares, repair man-hours, and support infrastructure. Additionally, adequate bandwidth must be provided to support Network Centric Logistics.

(3) Recognizing that a Level Of Repair Analysis (LORA) has not been completed, the CROSSBOW concepts calls for Sea Archer to conduct only organizational level maintenance. All higher levels of maintenance are anticipated to be the responsibility of the Sea Quiver support ship, which should act like a tender for major repairs. Aircraft onboard Sea Archer may follow a similar plan and only conduct organizational level servicing, repair and troubleshooting. Remove and replace activities should be the emphasis. The Sea Quiver should be capable of recovering any Sea Archer aircraft on its flight deck.

2. Projected Threat

The threat to naval forces in 2020 will lie in the proliferation of high-tech/low-cost weaponry and sensors. These systems will be designed to inflict maximum damage by simple saturation of own-ship sensors and defensive measures.

a. Major Threat Areas

(1)   Space. Space may continue to represent the primary information conduit for U.S. forces - which includes, but is not limited to, Command and Control, targeting, and reconnaissance. New weapons should reach maturity whose purpose is to destroy these vulnerable assets - lasers and particle beams are examples, from the ground, the air, and space.

(2)   Air. UAVs may be the platform of choice for future combatants. The absence of pilot constraints, namely G-forces, will allow designers to incorporate radical maneuvering capabilities. UAVs are also generally less expensive than their manned counterpart. This may lead to attacks of large numbers of aircraft, most small, difficult to detect, and once detected difficult to counter due to it exceptional maneuverability. With advances in propulsion systems, new long range cruise missiles should have loiter and wait capabilities that far exceed those of today. And with the miniaturization of explosive ordnance, much smaller missiles are likely. Payloads for tomorrow's high-altitude aircraft may include precision guided munitions, lasers, particle beams, and EMP weapons.

(3)   Surface. Large numbers of advanced, relatively inexpensive long range Anti-ship Missiles (ASMs) may be employed against our forces. Grand sea battles will be fought over the horizon (OTH), much akin to those of WWII carrier duels.

But in this case, ASMs and UCAVs may replace manned fighters, bombers, and torpedo planes. Torpedo technology will enable extremely long-range torpedoes to be sent to loiter or wait in standby on the bottom. Extremely high-speed torpedoes may be capable of overtaking even the fastest of surface ships.

        (4)   <u>Undersea</u>. Nations will employ generation after next submarine technology, including the capability to mask in the noise of the ocean, making them virtually undetectable. These submarines may be capable of deploying ultra-high explosive mines, extremely high-speed torpedoes, Special Forces, and missiles.

        (5)   <u>Info-sphere</u>. Information Warfare poses a threat to secured communications networks that can be attacked directly, and anonymously, by foreign powers or terrorist organizations. Traditional military weapons are ineffective against enemy information operations. Indeed, adversaries may use electronic espionage, sabotage, psychological warfare attacks, digital deception, and hacker attacks to neutralize our traditional forces. Command and Control nodes may be the targets of choice.

b.   Common Threads Amongst These Threats Include

(1) Enhanced multi-source intelligence collection and Information Warfare Operations.

(2) Enhanced tactical mobility systems that reduce reaction time, protect the littorals, and improve firepower and sea protection.

(3) Higher-volume, longer-range targeting, command, control, and communications.

(4) Enhanced counter-mobility capability by using land and shallow water mines.

(5) Increased availability, numbers and accuracy of precision guided munitions.

(6) Increased lethality and reliability of weapon systems [The possible use of Weapons of Mass Destruction (WMD)].

(7) Electronic Warfare (EW) capabilities to monitor, direct find, jam and deceive in the Radio Frequency (RF) and electro-optical spectrums.

(8) Early attack and disruption of supplies and logistics.

(9) The ability to reach into the blue water ocean with submarines, smart mines and aircraft carriers.

(10) Ability to take advantage of the sea and land terrain close to shores.

(11) Own system saturation due to number of aircraft, missiles, and rockets in the air at the same time, dramatically increasing the probability of attrition.

3. Shortcoming of Existing Systems

There is no existing system with the capability the Sea Archer is being asked to provide. The emergence of UAVs / UCAVs, the continued U.S. Navy focus on the littorals, the desire for force distribution, the need for operational cost reductions, and the advent of Network Centric Warfare (NCW) all combine to support a requirement to re-think how future warfare will likely be waged in the littoral. A ship has never before been designed, from the bottom up, to support the operation of a primarily UAV / UCAV air wing in a high-threat environment. Sea Archer will be the first. The CVBG projects power and dominates the blue waters in which it sails. The object of the CROSSBOW Battle Group is to augment CV capabilities in the contested littorals of the world.

4. Operational Constraints

a. Environmental

Sea Archer should remain fully operational in all environments up to and including sea state 4 (threshold)/5 (objective), regardless of time of day, whether conducting independent or force operations, in heavy weather or in the presence of electromagnetic interference, or chemical, biological, or radioactive (CBR) contamination. Internal operating spaces should have full CBR protection, and hanger decks at least conditional (personal protection required). Automated Damage Control (DC) should be provided. Sea Archer should be able to transit through sea state 6. Sea Archer minimum operational water depth should be commensurate with the littorals of the world to within 20nm of the beach (threshold), 10nm (objective).

b.   *Maneuverability*

Sea Archer should be capable of sustained speeds of 40 knots (threshold), and 60 knots (objective). Operational speeds of 60 knots for 20 minutes (threshold), 40 minutes (objective) are necessary for optimal air operations under light wind conditions. For air operations, ship motion should not exceed 3 degrees pitch, 8 degrees roll, and vertical accelerations of 0.5g.

c.   *Staying Power*

It is assumed that the Sea Quiver supply ship would have similar transit speeds and should accompany a squadron of Sea Archers on deployment. Sea Archer should be capable of sustained combat operations of three days (threshold) / seven days (objective) without re-supply. A CROSSBOW Battle Group should be capable of 90 days of self-sustained peacetime operations

d.   *Size/Cost*

Sea Archer should be able to use current USN port facilities. Sea Archer must be small enough to ensure that force distribution (squadron of 6-8 ships) is affordable and yet large enough to launch and recover the CROSSBOW air wing. A squadron of Sea Archers and their air wing should be roughly equivalent, in cost, to a CV and its air wing. It is desired that the Sea Archer be PANAMAX constrained; however, this should be considered trade space. If radical new hull designs that force PANAMAX to be exceeded make significant contributions to performance, then the requirement will be reconsidered.

5.   Required Capabilities

a.   *Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)*

(1)   Network Centric Warfare (NCW). NCW is an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledgeable entities in the battle space. Incorporation of NCW concepts is necessary for CROSSBOW to be

an effective force. The Distributed Sea-based Air concept demands a highly flexible Command and Control Architecture with system multiplicity, and redundancy built-in to ensure total system availability and enhanced survivability during combat and non-combat operations. Therefore, all Sea Archer ships should have the same command and control capability. Sea Archer C4ISR should share tactical and administrative information using advanced networks and technologies. These new resources will continue to automate manual processes, but should also improve decision support functions through advanced modeling and simulation. Sea Archer's information architecture should be designed to optimize interoperability, data access, information sharing, managed security and reliability of service while reducing data redundancy and costs.

          (2)   Interoperability. Sea Archer's communications architecture must be fully interoperable with other naval, expeditionary, interagency, joint and allied information systems. A coherent tactical picture is necessary to support Joint Force, Battle Force, Battle Group and Air Wing planning, coordinate actions with other forces, and communicate the force's actions to appropriate commanders. Sea Archer must have the necessary command and control architecture to communicate with a Joint Force Commander (JFC). Additionally, it is necessary to leverage NCW to fully integrate sensor and shooter into an effective and potent fighting force. The Defense Information Infrastructure (DII) Common Operating Environment (COE) should be used.

          (3)   Control of UAVs & UCAVs. The Sea Archer should have responsibility for control of unmanned air vehicles within its air wing. Direct control may be transferred to other elements or other Sea Archers depending on the mission.

          (4)   Commander of Task Force (CTF). The size of any given operation will determine who the CTF is and where he/she and staff are located. All Sea Archers should be equipped to handle command and control, but should not be designed to accommodate a CTF staff.

          (5)   Information Warfare (IW). IW is the ability to exploit, corrupt, deny, or destroy an adversary's information base while leveraging friendly information and information systems to achieve Dominant Battle space Awareness. As

information technology continues to proliferate and as our susceptibility to Offensive IW increases, defensive IW enables full spectrum protection. The Sea Archer must be capable of 1) protecting its own information systems and 2) leveraging U.S. and allied information to gain a decisive advantage.

b.   *Humanitarian Operations*

Sea Archer should provide empty shelter space for accommodating 30-50 non-combatants in an emergency. This space may be used for crew recreation or enhanced survivability; it must not interfere with the ability of the ship to conduct normal functions, even with the additional passenger load onboard. At the Battle Group commander's earliest convenience, these non-combatants should be ferried to a Sea Quiver, CV, or other large combatant for longer-term support and transport.

c.   *Survivability/Vulnerability*

Sea Archer must be able to operate aircraft in hostile environments, protect itself from enemy attack, and if hit, degrade gracefully and remain afloat (threshold); / remain afloat and launch air wing for recovery on sister ships, Sea Quiver, or CV (objective). The ship survivability performance must support damage control operations in a reduced manning environment. To reduce vulnerability in the littorals, the ship should be equipped with enhanced survivability features, such as in-stride mine avoidance capability and full-spectrum signature reduction (Radio Frequency/Infra-Red/Electro-Optical/Communications Conformal Apertures, reduced clutter, geometric shaping). Attention should be given to acoustic quieting and magnetic signature reduction for both equipment and propulsion systems. Inclusion of a damage-tolerant design, and an integrated magazine protection system should also be considered.

d.   *Self-Protection*

The ability to assess terminal threat situations quickly and correctly will be an essential element of Sea Archer's weapon systems. Shipboard defense capabilities should provide a protective shield against cruise missiles, submarines, torpedoes, mines, aircraft and other future threats. The defensive weapon systems selected must have high precision/accuracy, high probability of kill and high repetitive fire rates. The generation after next (2020) Close In Weapon System (CIWS) replacement and a shipboard version of something akin to the new Rapid Airborne Mine Clearance System (RAMICS) could

be candidates for consideration. Sea Archer should have integrated Electronic Warfare (EW) capability to support ship defense.

### e.	Special Operations

Sea Archer should have the capability to embark one SEAL platoon and their equipment. SEAL platoons should be embarked as required by the operational scenario. When SEALs are embarked, the multi-mission helicopters (e.g. H-60) needs to be a part of the air wing (rather than the attack helicopters) to provide an airborne insertion capability.

### f.	Inport Force Protection, Mooring, and Ship Access

Sea Archer should have the means to provide adequate Inport Force Protection and ship access control. Sea Archer should be able to be made fast to the ground, buoy, or pier and safely remain made fast in up to 30 knots of wind. These systems should be as automated as possible to minimize manning requirements.

### g.	Logistics Summary

- Prognostics / Diagnostics
  - Remote Sensing Virtual Presence
  - Ship & Airborne Assets
  - All linked
- Minimize Special Tools
- Access to Intermediate/Depot Level Repair Information
  - Damage Control / Battle damage scenarios
- Wireless Links to Tech Libraries (Throughout Ship)
- Remote Access to Requisitioning & Materials Support Info
- Design
  - Modular
  - Commercial Off The Shelf (COTS) where appropriate
  - Max use of Automation & Robotics
    - Yellow gear functions
    - Stock & Storage
    - Movement of provisions from/to flight deck
    - Fueling / Armament / Storage
- Replenishment

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- RAS / VERTREP / CONREP

  - High-speed UNREP with Sea Quiver

  - Helicopter & RAS staging areas port & starboard

  - Fuel / Liquid transfer stations port & starboard

- Weapons Storage

  - Small arms – SEAL platoon & Ships Company

  - New small smart munitions – 250 lb

  - Other airborne weapons

  - Missiles Rockets pods/ Mini-gun rounds / RAMAIC rounds….

  - Rounds for CIWS replacement

- Food stores / dry provisions / chill-freezers

  - Located near food preparation facilities

  - Capacity – 150 people for 3 months

  - Safe / reliable dumbwaiters for food transfer…

Habitability needs follow:

- Personnel

  - Notional – 150 (Threshold)

    - 25 Officers / 25 Chiefs / 100 Enlisted
  - 100 (Objective)

- Enlisted spaces – 4/Stateroom

- Refuse devices to reduce trash maintained onboard

  - Biodegradable meal containers

- Self-service crew services

  - Laundry

  - Ship's store

  - E-mail center

  - A/V room…

- Workload reductions

  - Wax-less floors

  - Endurance paints

  - Paint-less surfaces

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SEA ARROW

SEA ARROW AIRBORNE MISSION NEED STATEMENT FOR CROSSBOW
(Version 2)

A.   GENERAL DESCRIPTION OF OPERATIONAL CAPABILITY

    1.   Mission Area

    (1)   National Security Strategy has shifted from a focus on a global threat to a focus on regional challenges and interests in Littoral waters. While the prospect of global war has receded, we are entering a period of enormous uncertainty in regions critical to our national interests. Our forces can help to shape the future in ways favorable to our interests by underpinning our alliances, precluding threats, and helping to deserve the strategic position we won with the end of the Cold War. Naval Forces will be full participants in the principal elements of this strategy--strategic deterrence and defense, forward presence, crisis response, and reconstitution. The Naval White Letters Forward From the Sea (FFTS) and Operational Maneuver From the Sea (OMFTS) provide direction to the U.S. Navy (USN) and the U.S. Marine Corps (USMC) concerning the challenges of the post-Cold War world and shift the operational focus of naval forces from the open ocean to the world's littorals. The concept of Littoral Warfare emphasizes the capability of naval forces as a forward deployed crisis response force to deter conflict in the littorals, and to prevent escalation and restore stability where deterrence has failed. These Naval forces will meet far greater threats in numbers, quality and intelligence of weapons. As simultaneous coordinated attacks come with larger number of all types of weapons (from subsurface, surface, air and space), any Naval force will have far less time to plan and carry out defensive and offensive operations. This view of a combat operation in the time frame of 2020 will require a mix of all types of Airborne missions both manned and unmanned. For planning purposes, the Crossbow equipped task force will embark from San Diego for the South China Sea in September of 2021. All new Missions, Technologies, Equipment, and Operations Strategies must be validated, certified and practiced by Fleet Battle Experiments in the Summer of 2021.

    (2)   The state of the world in Asia in 2020 is defined by the final report of the SEI 1 class and the two books by Michael Pillsbury on China. With a far greater emphasis on joint and combined operations, the Navy, Marine Corps, Army and Air Force will provide unique capabilities of indispensable value in meeting our future security challenges especially in the littorals. Ready, relevant, and capable American

Naval Expeditionary Forces provide: a powerful yet unobtrusive presence, strategic deterrence, control of the seas, extended and continuous on-scene crisis response, precise power projection from the sea, and sea lift if larger scale war-fighting scenarios emerge. These maritime capabilities are particularly well tailored for the forward presence and crisis response missions articulated in the emerging National Security Strategy. The requirement for the capability to deploy, transport, and project landing forces in sufficient strength and capacity for the conduct of up through Marine Expeditionary Force (MEF) level amphibious operations without nearby land bases for support has been identified in the Marine Corps Master Plan (MCMP) 1996-2006.

(3)   Our ability to command the seas in areas where we anticipate future operations allows us to resize our naval forces and to concentrate on those capabilities required in the complex operating environment of the "littoral" or coastlines of the earth. Naval Expeditionary Forces maneuver from the sea using their dominance of littoral areas to mass forces rapidly and generate high intensity, precise offensive firepower at the time and location of their choosing, under any weather conditions, day or night. Operating in the Littorals requires mobility, flexibility and technology to mass strength against weakness in a timely manor.

(4)   Our National Security Strategy Requires a Strong Forcible Entry Capability into the littoral areas and adjacent land. As discussed in detail in the Department of the Navy's Concept of "From the Sea", America's interests will continue to dictate the necessity to influence events on the other side of our protective oceans. While even the viability of political reinforcement, by uncontested forward-presence forces, requires a credible forcible entry capability, the requirement to respond against an invader or international outlaw requires the unquestionable ability to place power in the littorals and ashore. Without an adjacent land base, the requisite sustainable, forcible entry capability can only come from the sea and new methods of supply and maintenance must be developed. Our forces will be required to enter areas defended by integrated systems of modern space, air, sea, and ground weapons. While some defenses will consist of relatively immobile forces and fixed positions, others will include mobile, combined-arms units-backed by space weapons, naval and air craft (manned and

unmanned) and employing the newest unmanned vehicles, missiles and mines against our planes, ships, and landing forces. Design of operations and forces to defeat these opponents must accommodate our structural intolerance of attrition and societal demands for inexpensive victory.

2.   Type of System Proposed

Title 10, U.S. Code, directs the Navy to develop equipment used for maritime operations.   This document addresses the operational capabilities and design considerations for the Airborne Operational family (Sea Arrow) to be associated with the Crossbow. The family of vehicles will consist of Manned and Unmanned Aircraft (with emphasis on Unmanned) to perform Defensive, Offensive, Fleet Support, and Military Operations Other Than War. A primary goal is to reduce casualties and win through deterrence. Figure 1 shows the trend in airborne missions over time. During the Second World War, every airborne vehicle carried munitions and was used for destruction of enemy forces. In the Gulf war there were on the order of 5 support airborne vehicles for every one that carried ordinance. It is expected that this trend will continue.

Figure 1
Number of support aircraft
per aircraft carrying
ordinance
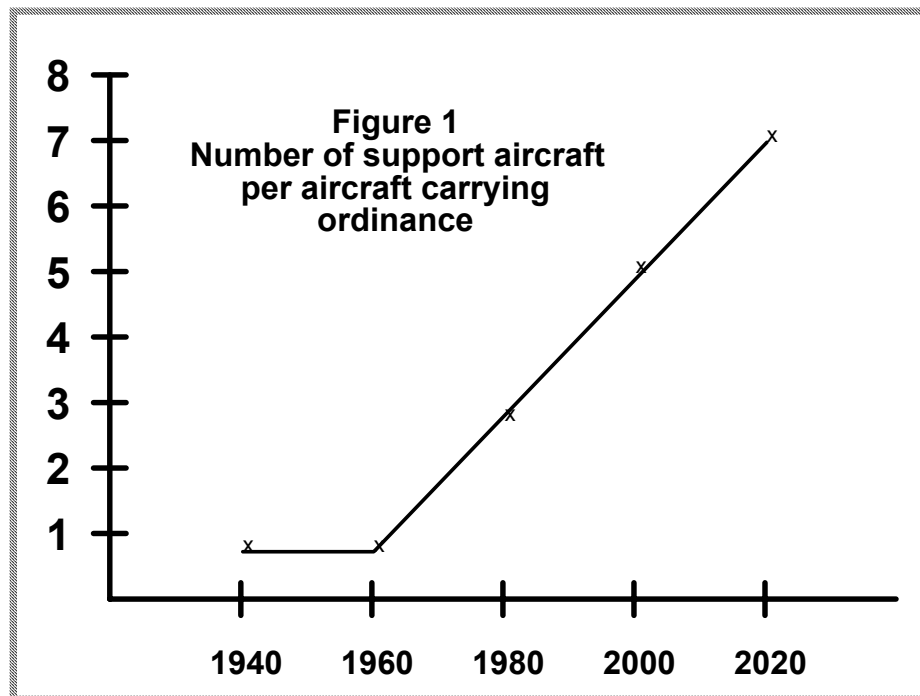
3. Operational Concept

(1) "From the SEA"(FTS) is a concept for projecting naval power in the littorals and ashore in support of a strategic objective. Essentially, FTS is the application of maneuver warfare principles to the maritime portion of a theater campaign, capitalizing on the ever expanding capabilities of modern naval airborne forces (manned and unmanned) to project power in an increasingly Sophisticated and lethal environment. Operations are designed to break the cohesion and integration of enemy defenses while avoiding attrition oriented attacks. Emphasis will be placed on speed, mobility, deception, surprise, and other measures of battlefield preparation that confuse or create uncertainty and delay in the enemy's actions. Our ultimate desire is to destroy his will to fight or carry out actions contrary to the interests of the United States.

(2) FTS is a single, seamless operation extending from homeports to secure sea bases across the littoral to dominate a critical enemy center of gravity. The FTS concept requires a single force that can change its character with its environment but always operate with a single objective. FTS brings all facets of sea power to bear; it replaces our recent history of separately controlled movement, supporting operations, landings, and maneuver ashore with collaboration founded on Network Centric Warfare. The next generation of technology provides our opportunity to close the battlefield mobility gap between space assets, airborne operations, ship firepower and on shore forces, to link maneuver in ships, space assets, airborne operations with maneuver ashore.

(3) Increased operational speed will be the sum of more rapid decisions of command, faster methods of control, quicker execution, higher speed of airborne systems, and ever diminishing friction in the transition from maneuver at sea to maneuver in the littorals. Relative operational (speed the difference between our speed and that of the enemy) will increase as enemy operations are degraded by simultaneous surprise, deception, strikes, fires, and special / information operations. The moment of achieving superior operational tempo will be reached when the frequency of our operations do not allow our opponent to respond effectively or maintain cohesion of his forces.

(4) While strike and special operations are complementary forms of sea power projection, new technologies, equipment, and tactics will be required to allow the

Crossbow force to gain superiority in the littorals. The conduct of a littoral operation encompasses almost all types of ships, aircraft, weapons, and landing forces of the U.S. Navy and Marine Corps in a collaborative military effort. The salient requirement of the littoral operation is the necessity of rapidly building up combat power from an initial level of zero to full coordinated striking power to gain success and maintain objectives.

(5)   Naval Crossbow forces will be structured and equipped to project combat power in the littorals to seize control of the crisis arena for follow-on joint operations. Power projection requires air, space and water mobility, speed, firepower, and a versatile mix of survivable vehicles that enable launch in nearly all weather from a sea base of versatile ships. Crossbow is not intended to act alone; but could act alone under special circumstances. The force provides standoff (battle space) for the Naval Task Force to enable the effective employment of active / passive defense systems against enemy air and surface-fired weapons, avoids the major sea mine threat and avoids attrition. The battle space will be very complex around the task force with large numbers of enemy and friendly manned and unmanned vehicles in the air, Figure 2.

FIGURE 2 -- PLEIADES TECHNOLOGICAL CONCEPT
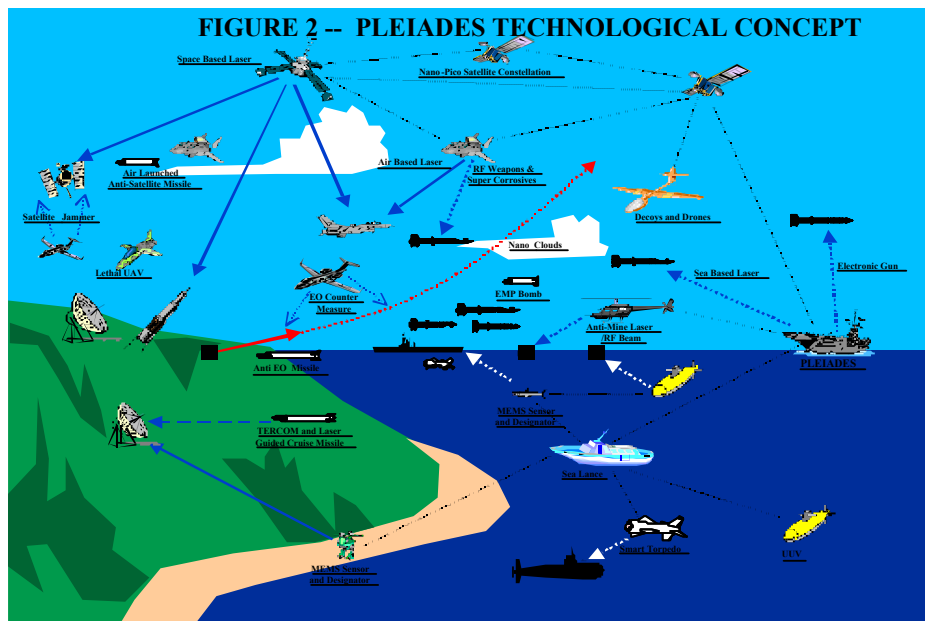
(6) As part of the Navy after Next initiative the Navy plans to introduce squadrons of small expeditionary aircraft carriers (approximately 7 –actual number yet to be

determined) designed to operate in concert with up to 20 Sea Lance, small, low cost, high-speed combatants capable of deploying the Expeditionary Warfare Grid. This new force shall operate primarily in the littoral environment and be capable of operations independent of or with support from a CVN battle group for short periods of time during Military Operations Other Than War and low intensity conflicts.

(7) The unmanned vehicles shall be optimized for missions characterized by "The Dull, the Dirty, and the Dangerous".

4. Support Concept

It is intended that the Crossbow Airborne Vehicles-Sea Arrows - can be operated and maintained by sailors and marines with skill levels generally commensurate with those currently in the Navy. Logistic support and maintenance for the airborne vehicles must be performed within the existing logistic support organizational structures as defined by "Network Centric Logistics". The Navy supply support system will provide timely acquisition, distribution, provisioning, and inventory replenishment of system components, spares, repair parts and consumable supplies necessary to maintain the airborne vehicles in a high state of readiness. Supply planning will be closely coordinated with maintenance planning during all phases of the development to ensure timely availability of supplies to meet provisioning and replenishment requirements from Initial Operational Capability (IOC) through Full Operational Capability (FOC).

5. Threat

a. Time Frame

The threat to naval forces in 2020 will encompass the entire operational spectrum of military capabilities ranging from dissident/guerrilla forces to sophisticated first line equipped, regular forces. These threats are detailed in the China Area Denial Study of 1998, the two books on China by Michael Pillsbury, and the final report of SEI 1. Anticipated threat objectives will be the coordinated effort to use all target acquisition and force support agencies available for the purpose of denying the combat power of the littoral force during the initial stages of ship movement. Central to the threat's defensive plan is the early identification and rapid denial in the littorals.

b.   *Common Threads*

Common threads of future **threat** capabilities include:

- Enhanced multi-source intelligence collection and Information Warfare Operations

- Enhanced tactical mobility systems that reduce reaction time, protect the littorals, and improve firepower and sea protection

- Higher-volume, longer-range precision targeting, command, control, and communications

- Enhanced counter mobility capability by using land and shallow water mines

- Increased availability, numbers and accuracy of precision guided munitions

- Increased lethality and reliability of weapon systems [The possible use of weapons of Mass Destruction (NBC)]

- Electronic Warfare (EW) capabilities to monitor, direct find, jam and deceive in the Radio Frequency (RF) and electro-optical spectrums

- Elimination of US Space assets

- Early attack and disruption of supplies and logistics

- The ability to reach into the blue water ocean with submarines, smart mines and aircraft carriers

- Ability to take advantage of the sea and land terrain close to shores

- Information Operations (IO)

- With so many aircraft, missiles, & rockets in the air at the same time, the probability of attrition is very high

6.   **Shortcoming of Existing Systems**

a.   *Background*

The current manned aircraft were put into service in the 1970's and 1980's. Major service life extension programs are underway and, coupled with depot level maintenance programs, extended service lifetimes are projected into the 21st century. Despite an extensive product improvement program, the current airborne vehicles are limited in survivability in all threat environments of the future.

b.   *Overview*

The CVN battle group projects power and dominates the blue waters in which it sails.   The object of the CROSSBOW battle group is to augment CVN capabilities in the contested littorals of the world.

The CVN's advantage of concentrated power is so serious a liability in unsafe waters that no one would risk it in dangerous contested regions without an extended and arduous period of softening up. For this reason it will have a difficult time providing cover for the Sea Lance ships and Marines operating inside 100 nm of the beach.

The future sea based distributed aviation concept goes beyond the distribution of the carrier platform.   Distributed, reliable and survivable airborne platforms will help to provide graceful degradation of capability during combat engagements.

Existing naval airborne platforms were designed to operate from a CVN and in most cases are too large to operate from a 10-20 thousand ton ship. Additionally, manned aircraft were put into service in the 1970's and 1980's are obsolete. The only close in aircraft developments that can be considered for this future force are JSF, V-22, and the SH/CH-60. If the VSTOL version of the JSF is considered as part of the Crossbow air wing of Sea Arrows, the ship may become unaffordable. A full squadron of Crossbow ships (4 plus) including the air wing should be roughly equivalent, from a cost perspective, to a CVN with its air wing. A variant of the H-60 should certainly be considered when exploring ways to meet the airborne requirements, but only a small number (2-3) is likely to be supportable from each ship.

Historically, opportunities for revolutionary change in the military are rare. Let us take full advantage of all unmanned vehicles!

7.   **Specific Airborne Missions for CROSSBOW**

a.   *General*

A significant number of airborne missions must be launched from the expeditionary aircraft carriers to support a Crossbow Battle force operating in the littoral

environment. It is anticipated that Crossbow will operate with a minimum of 4 expeditionary aircraft carriers. No single airborne platform, Sea Arrow - is expected to accomplish all of the required missions and all missions do not need to launch from a single expeditionary carrier. It is recognized that some missions may require the simultaneous operation of more than one of any given airborne platform type. However, the total airborne system shall maximize modularity, replace ability and commonality to minimize total operating / lifecycle costs. All maintenance will be done by replacing modules. The mission MTBF shall be 100 times the defined total mission time (Fly to station + On station time + Fly back to the Crossbow). A high priority is for all airborne platforms designed to meet this mission statement shall use the same fuel as the ship and be launch-able from either the Crossbow or a modified Sea Lance; but only need to be recoverable on the Crossbow.

Firepower and other performance characteristics equivalent to CVN based aircraft are NOT required. The airborne system for CROSSBOW shall be scaled for the littoral missions and provide complementary capabilities for operations conducted in concert with a CVN Battle Groups, see Figure 3. The shipboard pilot shall maintain safety of flight responsibilities during all hand-off activities.

Even though this a Mission document, for initial trade-offs and design efforts the following can be assumed regarding the CROSSBOW ship – Sea Archer:

- Wind over the deck of 20 knots will always be available
- Wind over the deck of up to 70 knots can be expected
- At least one electromagnetic catapult can be provided:
    - Length – (1/4 length of smallest ship)
    - Acceleration capability: adequate.
- Launch & Recovery
    - Maximum Pitch – 3 degrees
    - Maximum Roll – 6 degrees
    - Vertical Acceleration - .5

Figure 3

```
                        Airborne Missions
         ┌──────────────┬──────────────┬──────────────┐
     Defensive       Offensive    Fleet Support      MOOW
  ┌────┬────┬─────┐                ┌──────┐         ├─ ISR
 ISR  MCM TMD  CSAR              B/U GPS Logistics  └─ Embargo.
  │                                                  VERT/REP
  ├ Short Range                                      Personnel Trans./  Medivac
  │  + BDA                Soft  Hard  MIW  SOF  BDA   Mail
  │                       Kill  Kill      Support     Comms / Data Relay
  └ Long Range                         Targeting      SAR
                          │EA    ├ CAS  ├ Team Transport  ├ Cruise Missiles
                                 ├ CAP  ├ Self-defense
                                 ├ ASW  ├ Message Drop    ├ A/C launched smart munitions
                                 ├ Anti-ship
                                 └ Battle Field Interdiction ├ Guided Artillery
```

The missions, technologies and program developments shall be in accordance with the "Unmanned Aerial Vehicles Roadmap – 2000 to 2025" dated April 2001 from the Office Of The Secretary of Defense. The theme of the Crossbow MNS is the same as the theme of this roadmap -- **The unmanned vehicles shall be optimized for missions characterized by "The Dull, the Dirty, and the Dangerous**".

B. MISSIONS BY FUNCTION

1. Offensive Missions

a. Combat Air Support (CAS)

Provide spontaneous fires in support of ground forces operating in the littoral environment (shoreline to 100 nm inland). Forward Air Controllers (FACs) shall be provided the capability of local control.

- Combat Radius – 200 nm
- Loiter – 2 hours (threshold); 4 hours (objective)
- Max Cruise Speed – 1 M (threshold); 2 M (objective)
- Payload Capacity – 1,000 Lbs *

b. Combat Air Patrol (CAP)

Complement shipboard defensive systems, with Airborne Radar.

- Combat Radius – 100 nm
- Loiter – 4 hours (threshold); 8 hours (objective)

- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective)
- Payload Capacity – 1,000 Lbs *

c. Battlefield Interdiction (BI)

Deliver smart munitions on high value targets in the littoral environment (shoreline to 100 nm inland).

- Combat Radius – 200 nm
- Loiter – 2 hours (threshold); 4 hours (objective)
- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective)
- Payload Capacity – 1,500 Lbs *

d. Suppression of Enemy Air Defenses (SEAD)

Inflict mission kill damage to enemy air defense radars (out for 12+ hours) with HARM like weapons scaled to the mission and 2020 technology:

- Combat Radius – 200 nm
- Loiter – 2 hours (threshold); 4 hours (objective)
- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective)
- Payload Capacity – 1,500 Lbs *

e. Anti-Submarine Warfare (ASW)

Airborne ASW shall operate in concert with surface units, CVN assets, and/or land-based ASW assets in the AOR to maintain contact with and targeting information on all enemy subs operating within the vicinity of the battle group.

- Combat Radius - 100 nm;
- Loiter Short Range – 4 hours (threshold); 8 hours (objective)
- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective).

f. Precision Kill Targeting and Designation

Pass precise targeting data for cruise missile terminal guidance

- Combat Radius – 200 nm
- Loiter – 2 hours (threshold); 4 hours (objective)
- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective)
- Payload Capacity – 1,000 Lbs*

g. Signal Intelligence and Electronic Warfare

Monitor enemy electronic emissions

- Combat Radius – 200 nm

- Loiter – 4 hours (threshold); 6 hours (objective)

- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective)

- Payload Capacity – 1,000 Lbs *

h.   Mine Delivery

Deliver micro / nano mines of all types within the AOR

- Combat Radius – 200 nm

- Loiter – 2 hours (threshold); 4 hours (objective)

- Max Cruise Speed – 0.6 M (threshold); 0.8 M (objective)

- Payload Capacity – 1,000 Lbs *

i.   ASW Weapons

Deliver torpedoes and Depth Charges to destroy submarines and mine fields.

- Radius of action – 100 nm

- Loiter – 6 hours (threshold); 8 hour (objective)

- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)

- Payload Capacity –1,000 Lbs *

j.   Anti – Satellite/Space Warfare

Protect naval and littoral operations from interference from space surveillance, targeting and attack.

- Combat Radius -- Out to 1000 nm arc length from the task force.

- Altitude - Out to synchronous orbit.

- Loiter – 4 hours (threshold), 6 hours (objective)

- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)

- Payload Capacity – 1,500 Lbs *

C.   DEFENSIVE MISSIONS

1.   Intelligence Surveillance and Reconnaissance (ISR)

The ISR suite shall provide expeditionary commanders operating in the littoral area with near-real time data required to support active and passive surveillance requirements independent of, or in concert with, CVN battle group assets, or reliance on limited Joint Theater or National Assets.

- Radius of action Short Range = 100 nm; Long Range = 200 nm

- Loiter Short Range – 2 hours (threshold); 4 hours (objective)

- Loiter Long Range – 4 hours (threshold); 6 hours (objective)

- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)

- Payload Capacity Short Range – 500 Lbs *

- Payload Capacity Long Range – 1,500 Lbs *

2.   Battle Damage Assessment

Provide intelligence to the battle group regarding damage inflicted.

- Radius of action – 200 nm

- Loiter – 30 minutes (threshold); 1 hour (objective)

- Max Cruise Speed - .1M (threshold); .2M (objective)

- Payload Capacity – 500 Lbs *

3.   Support of Special Operations Forces (SOF)

PSIOP and covert sensor placement. Locate mines in the littoral (bottom & volume), and Mark mines for neutralized. Deploy decoys, deliver Information Warfare leaflets over enemy controlled territory and Transport/recover Navy Seal team behind enemy lines

- Combat Radius – 300 nm

- Loiter – 30 minutes (threshold); 1 hour (objective)

- Max Cruise Speed - .0.6 M (threshold); . 0.8M (objective)

- Payload Capacity – 500 Lbs *

4.   Theater Missile Defense

Detect and provide targeting for Tactical Ballistic Missiles and launch sites precision strikes.

- Radius of action– 100 nm at 80 K Feet

- Loiter – 4 hours (threshold); 6 hours (objective)

- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)

- Payload Capacity – 1,500 Lbs *

5.   Combat Search and Rescue

Search for and locate downed aircrews (Over land & Over water), Recover downed aircrews under fire. Direct fire when fired upon as required

- Combat Radius – 200 nm
- Loiter – 4 hours (threshold); 6 hours (objective)
- Max Cruise Speed – 0.6M (threshold); 0.8M (objective)
- Payload Capacity – 500 Lbs*

D.   FLEET SUPPORT MISSIONS

1.   Local Navigation System (GPS Like) Pseudolite

Provide local navigation to the same accuracies as GPS up to 1000 nm from the task force for those systems with modified GPS receivers. This signal will be broad band and anti-Jam

- Radius of action– 100 nm at 80 K Feet
- Loiter – 4 hours (threshold); 6 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 500 Lbs *

2.   Logistics / Team Re-Supply

Perform the following: Personnel Transfer/Medivac, Mail pick up and delivery, Communications / Data Relay, and Network Centric Logistics.

- Radius of action– 200 nm
- Loiter – 30 minutes (threshold); 1 hour (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 500 Lbs *

3.   Communications Relay

Relay VHF/UHF transmissions within the theater of operations

- Radius of action– 100 nm
- Loiter – 4 hours (threshold); 6 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 500 Lbs *

4.   Detect WMD Effects

Detect Nuclear, Biological, & Chemical materials in the atmosphere.

- Radius of action– 200 nm
- Loiter – 4 hours (threshold); 6 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)

- Payload Capacity – 500 Lbs *

5. Meteorology & Oceanography Detection

Provide Weather and Ocean conditions.

- Radius of action– 200 nm
- Loiter – 4 hours (threshold); 6 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 1,000 Lbs *

6. Digital Mapping

Develop and transmit Digital Maps of unknown terrain.

- Radius of action– 200 nm
- Loiter – 4 hours (threshold); 6 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 500 Lbs *

E. MILITARY OPERATIONS OTHER THAN WAR

1. Embargo Enforcement

Perform the following: Transport law enforcement detachment to target vessel, Conduct recon of vessel, & Deliver micro UAVs or nano sensor technology for detailed inspection or tracking

- Radius of action (un-refueled) – 100 nm
- Loiter –2 hours (threshold); 4 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 500 Lbs *

2. CNN Direct

Provide a direct CNN satellite feed from the area of conflict. Used as a deterrent to show an enemy that continued hostilities is useless.

- Radius of action (un-refueled) – 100 nm
- Loiter –2 hours (threshold); 4 hours (objective)
- Max Cruise Speed - .0.6 M (threshold); .0.8 M (objective)
- Payload Capacity – 500 Lbs *

F.   MISSIONS BY PAYLOAD WEIGHT*

All of the mission Functions defined above are also categorized by Payload weight (the numbering system uses the same numbers as the **Missions by Function**).This should help in the development of Modular capabilities.   Each of the following is assumed to carry **250 Lbs** of Avionics and Control Equipment.

1.   500 Lb Maximum Payloads

a.   Anti-Submarine Warfare (ASW)

- Towing Array of Hydrophones = 200 Lbs
- UHF Transmitter = 50 Lbs

OR

- 2 Small Torpedoes = 100 Lbs/each
- Launching Rack = 50 Lbs

b.   Intelligence Surveillance and Reconnaissance (ISR): - Short Range

- Search Radar = 150 Lbs
- Visual Camera = 50 Lbs
- UHF Transmitter = 50 Lbs

c.   Battle Damage Assessment

- BDA Radar = 125 Lbs
- Visual Camera = 50 Lbs
- UHF Transmitter / Recorder = 75 Lbs

d.   Support of Special Operations Forces (SOF)

- 10 Sonoboys = 20 Lbs / each

OR

- 10 Land Sensors = 20 Lbs / each

OR

- Pallet of Leaflets = 200 Lbs

e.   Combat Search and Rescue

- (a) Search Radar = 150 Lbs
- (b) Visual Camera = 50 Lbs
- (c) UHF Transmitter = 50 Lbs

f.   Local Navigation System (GPS Like) Pseudolite

- GPS Receiver = 50 Lbs
- High Power GPS Transmitter = 200 Lbs

g.   Communications Relay

- VHF / UHF Receiver = 50 Lbs
- VHF / UHF Transmitter = 200 Lbs

h.   Detect WMD Effects

- Nuclear Sensor = 25 Lbs
- Biological Sensor = 75 Lbs
- Chemical Sensor = 50 Lbs
- UHF Transmitter (medium power) = 100 Lbs

i.   Digital Mapping

- TERCOM (MMW) = 200 Lbs
- UHF Transmitter = 50 Lbs

j.   Embargo Enforcement

- Search Radar = 150 Lbs
- Visual Camera = 50 Lbs
- UHF Transmitter = 50 Lbs

k.   CNN Direct

- Video Camera = 50 Lbs
- Satellite Link = 150 Lbs

2.   1,000 Lb Maximum Payloads

a.   Combat Air Support (CAS)

- 24 – MK 76 (Improved) = 30 Lbs / each

b.   Combat Air Patrol (CAP)

- 2 – Sidewinder (Improved) = 125 Lbs / each
- Airborne Track Radar = 500 Lbs

                        OR

- AMRAM (Improved) = 250 Lbs
- Airborne Track Radar = 500 Lbs

c. *Precision Kill Targeting and Designation*

- Precision Track Radar = 300 Lbs

- LADAR = 250 Lbs

- LASER Designator = 150 Lbs

- UHF Transmitter = 50 Lbs

d. *Signal Intelligence and Electronic Warfare*

- Receiver (Signal Intelligence) = 150 Lbs

- VHF/UHF Transmitter (High Power) = 550 Lbs

- UHF Transmitter = 50 Lbs

e. *Mine Delivery*

- 24 Mines(Improved) = 30 Lbs / each

f. *ASW Weapons*

- 12 MK 76 (Improved) = 30 Lbs / each

- Track Radar = 200 Lbs

- Visual/IR Tracker = 15 Lbs

- UHF Transmitter = 50 Lbs

OR

- 12 Depth Charges = 30 Lbs / each

- Track Radar = 200 Lbs

- Visual/IR Tracker = 15 Lbs

- UHF Transmitter = 50 Lbs

g. *Logistics/Team Re-Supply*

- Smart Pallet = 700 Lbs

h. *Meteorology & Oceanography Detection*

- LASER for Environmental Evaluation = 200 Lbs

- Weather Radar = 200 Lbs

- Atmospheric Sensors = 200 Lbs

- UHF Transmitter = 50 Lbs

3.   1,500 Lb Maximum Payloads

   a.   Battlefield Interdiction (BI)

- 4 – Bombs = 250 Lbs / each

- LASER = 200 Lbs

   b.   Suppression of Enemy Air Defenses (SEAD)

- 4 – HARMS = 300 Lbs / each

   c.   Anti – Satellite / Space Warfare

- ASAT = 1,000 Lbs

- High Altitude Radar = 200 Lbs

- UHF Transmitter = 50 Lbs

                              OR

- 3 – Surveillance Satellites = 400 Lbs/each

                              OR

- 3 – Communications Satellites = 400 Lbs / each

   d.   Intelligence Surveillance and Reconnaissance (ISR) – Long Range

- J STARS (Improved) = 1,200 Lbs

- UHF Transmitter = 50 Lbs

                              OR

- Search Radar = 500 Lbs

- LADAR = 250 Lbs

- IR Imaging Sensor = 350 Lbs

- UHF Transmitter (Medium Power) = 100 Lbs

   e.   Theater Missile Defense

- High Altitude / Long Range Search Radar = 600 Lbs

- Multi- Spectral IR Sensor = 500 Lbs

- UHF Transmitter (Medium Power) = 100 Lbs

APPENDIX C. ROADMAP

ROADMAP

Technology-Methodology	ORGANIZATION	POC	PHONE	E-MAIL
Advanced Ship Concepts-Information Sys Integration	DD-X PEO	Dilisio, Mr. F. Scott	(202) 781-2569 DSN: 326	dilisiofs@navsea.navy.mil
Aging Aircraft	Aging Aircraft office, ASC/SMA	Hart, Major Karl	(937) 255-7210 x3810	Karl.Hart@wpafb.af.mil.
Aging Aircraft	Naval Postgraduate School	Eaton, RADM (ret) Don	(831) 656-3616	deaton@nps.navy.mil
Aging Aircraft Methods-Concepts	NAVAIR 4.1 - Aging AC	Ernst, Bob (Aero Eng)	(301) 342-2203	ErnstRP@navair.navy.mil
Automatic Identification Technology	NAVSUP & DoD Logistics AIT Office	Benjamin Morgan & Daniel Kimball	(717) 605-6793 DSN: 430	benjamin_b_morgan@navsup.navy.mil
Autonomic Logistics for JSF	JSF Deputy PM Logistics	Bodnar, Mr. Al	(703) 601-5622	bodnaraf@jast.navy.mil
Autonomic Logistics for Marine Task Force	HQ Marine Corps	Wagner, Major Chris USMC		
Depot Level Production Methods	NADEP North Is F/A-18C PM	Delaware, Mr. Shawn	(619) 545-3512 DSN: 735	DelawareLS@navair.navy.mil
Executive Data System (CAFSIS)	NAVAIR CF-18 Program Office	Senkel, Mr. Rich	(301) 757-7556 DSN: 757	senkelrm@navair.navy.mil
Former Age Exploration Team Member	NADEP North Island	Peranteau, Steve	(619) 545-3730 DSN: 735	PeranteauGS@navair.navy.mil
Integrated Diagnostics, Supply Chain Management, System Sustainment, Integrated Data	GA Tech Logistics and Research Applied Maintenance Center	O'Neill, Gary	(404) 385-1581	gary.oneill@gtri.gatech.edu
Integrated Diagnostics, Supply Chain Management, System Sustainment, Integrated Data	GA Tech Logistics and Research Applied Maintenance Center	Wagner, Ron	(404) 894-3357	ron.wagner@gtri.gatech.edu
Life Cycle Cost Model	Northrop Grumman Information Technology Defense Enterprise Sol	Calvo, Mr. Alberto	(781) 205-7112	abcalvo@tasc.com
NALDA 3M data	Naval Aviation Logistics Data Analysis	Yates, AZ1 James	(301) 757-3103 DSN: 757	YatesJP@navair.navy.mil
Naval Aviation Maintenance Initiatives to Support Focused Logistics in a Network-Centric Environment	NAVAIR (AIR 3.6B)	Mishler, Dr John W. III	(301) 757-8896 DSN: 757	MishlerJW@navair.navy.mil
Navy Culture	Naval Postgraduate School	Eaton, RADM (ret) Don	(831) 656-3616	deaton@nps.navy.mil
Network Centric Environment	NAVAIR (AIR 3.6B)	Mishler, Dr. John W., III	(301) 757-8896 DSN: 757	MishlerJW@navair.navy.mil
PHM Savings	Northrop Grumman Supportability & Naval Integration	Hodson, Mr. Bob	(310) 332-4586	HodsoRo@mail.northgrum.com

Reliability Centered Maintenance	NAWC Lakehurst, NJ	Regan, Nancy A	(617) 921-5408	ReganN@navair.navy.mil
Robotic Technologies	Inuktun Services Ltd.		(877) 468-5886	http://www.inuktun.com/custom.htm
Rotorcraft Health and Monitoring System	Sikorsky Aircraft	Kell, Ted	(203) 384-7336 or 7742	
Serial Number Tracking (SNT)	NAVSUP Fleet Logistics	Hayes, LCDR (SC) William R.		William_R_Hayes@navsup.navy.mil
Strategic Logistics, Cultural Issues	LMET, Logistics Engineer	Moore, Robert (Brev)	(410) 757-6319	bmoore@lmeinc.com
Supportability & Naval Integration UCAV-N	Northrop Grumman Supportability	Hodson, Mr. Bob	(310) 332-4586	HodsoRo@mail.northgrum.com
21st Century U.S. Naval Aviation Maintenance via Reliability Centered Maintenance	NAWC Lakehurst, NJ	Regan, Nancy	(617) 921-5408	ReganN@navair.navy.mil
Training Cost information and length of training by NEC	Naval Education & Training Professional Devel. & Tech Ctr (NETPDTC), Pensacola, FL	Smith, Mrs. Pat	(850) 452-1001 x1511 DSN: 922	Pat.smith@cnet.navy.mil
VTUAV support and funding concepts-Cultural issues	APML VTUAV Program	Wiggfall, LtCol Vic	(301) 757-5818 DSN: 757	WigfallV@navair.navy.mil
Data Management-Canadian Air Force	NAVAIR PMA265 CF-18 Liaison	Senkel, Rich	(301) 757-7556	SenkelRM@navair.navy.mil

APPENDIX D. PARAMETRIC MODEL

A.   METHODOLOGY AND ASSUMPTIONS

1.   Baseline Model and Input Data

The three worksheets in the NALDA baseline data [Naval Aviation Logistics Data Analysis, 2001] spreadsheet were labeled "Raw F/A-18 Data", "F/A-18 Filtered data – formulas", and "UCAV Comp". The "Raw F/A-18 Data" columns were totaled and summarized. The "F/A-18 Filtered data –formulas" worksheet contained edited data from the "Raw F/A-18 Data" sheet that eliminated unidentified WUC's. An example of this worksheet is seen in the example below.

	F-18C 5 DIGIT WUC SUMMARY											
	BOTH UN-SCHEDULED AND SCHEDULED MAINTENANCE											
	FROM APRIL 1996 - MARCH 2000 FLIGHT HOURS = 524,060											

WUC	NOMENCLATURE	MFHBF	Fail (4yrs)	Failures/YR	MFHBVF	V-FAILS	MTTR	MMH/MA	MMH	MMH/FH-O	MMH/FH-I	MMH/FH-T
03*****	MAINTENANCE INSPECTIONS	87343.33	6	1.50	104812.00	5	7.87	2.84	1063467.5	5.61566	0.00095	5.61660
04*****	CORROSION PREVENTION	262030.00	2	0.50	262030.00	2	4.87	2.12	363749.2	1.58839	0.00637	1.59476
05*****	GENERAL FUNCTIONS	30827.06	17	4.25	30827.06	17	6.77	1.77	11090.8	0.08057	0.00031	0.08087
09*****	NON-AERONAUTICAL WORK	8734.33	60	15.00	9035.52	58	3.51	2.67	975.3	0.00164	0.00080	0.00244
11*****	AIRFRAME	6.69	78322	19580.49	6.77	77416	5.17	2.38	481231.2	1.83068	0.07293	1.90362
12*****	FUSELAGE/COMPARTMENTS	140.95	3718	929.50	152.21	3443	2.86	1.60	20115.1	0.05623	0.01946	0.07571
13*****	LANDING GEAR SYSTEMS	10.35	50643	12660.67	11.36	46131	5.64	2.88	340697.3	0.91795	0.77381	1.69177
14*****	DIRECTIONAL FLIGHT CONTROL SYSTEMS	13.11	39973	9993.26	14.64	35804	9.40	3.86	321600.5	1.02986	0.43773	1.46762
17*****	ESCAPE SYSTEMS	55.21	9492	2373.01	59.74	8772	2.73	2.06	51873.1	0.10520	0.07485	0.18011
	Subtotal	171.10	182147.73	45536.93								
24*****	AUXILIARY POWER PLANT (AIRBORNE)	124.92	4195	1048.75	162.10	3233	7.59	3.84	28871	0.10216	0.03545	0.13761
29*****	POWER PLANT INSTALLATION	48.92	10713	2678.25	55.78	9395	4.95	3.17	58675.4	0.24616	0.03438	0.28054
41*****	ENVIRONMENTAL CONTROL/PNEUMATIC SYSTEM	26.41	19842	4960.50	32.85	15952	6.77	2.66	85148.9	0.33475	0.04196	0.37673
42*****	ELEC PWR SPLY/DISTRIB/LGHT SYSTEMS	37.85	13846	3461.49	45.78	11447	7.70	4.49	116257.8	0.24274	0.26851	0.51130
44*****	LIGHTING SYSTEMS	39.88	13140	3285.02	42.25	12403	4.68	2.09	39547.7	0.12288	0.05270	0.17559
45*****	HYDRAULIC/PNEUMATIC POWER	38.52	13606	3401.48	41.68	12572	7.76	3.18	66338.7	0.23415	0.05235	0.28649
46*****	FUEL SYSTEM	31.39	16697	4174.23	38.01	13786	8.53	1.91	91662.6	0.46704	0.02321	0.49024
			0			0			0.0			
47*****	OXYGEN SYSTEMS	195.33	2683	670.75	272.10	1926	4.24	2.51	17717.3	0.03354	0.03340	0.06693
49*****	MISCELLANEOUS EMERGENCY/UTILITY SYSTEM	201.10	2606	651.50	237.99	2202	6.07	2.38	12063.6	0.04550	0.04550	0.04550
51*****	INSTRUMENTATION SYSTEMS	158.85	3299	824.75	192.17	2727	5.18	2.55	14875.0	0.05508	0.01272	0.06785
56*****	FLIGHT REFERENCE SYSTEMS	87.14	6014	1503.50	122.73	4270	6.23	2.25	22952.3	0.06851	0.04000	0.10851
57*****	INTEGRATED GUIDANCE/FLT CNTRL SYSTEMS	41.44	12646	3161.54	53.38	9817	7.41	3.33	85981.0	0.18889	0.25772	0.44664
58*****	IN-FLIGHT TEST EQUIPMENT SYSTEMS	50.51	10376	2594.03	62.69	8359	4.70	2.33	65684.1	0.12258	0.19563	0.31820
62*****	VHF COMMUNICATIONS SYSTEMS	69.12	7582	1895.51	83.50	6276	2.63	1.48	24834.9	0.07310	0.03159	0.10468
63*****	UHF COMMUNICATIONS	1838.81	285	71.25	2403.95	218	3.18	1.71	941.1	0.00354	0.00036	0.00392
			0			0			0.0			
64*****	INTERPHONE ASSOCIATED EQUIPMENT	150.85	3474	868.50	195.77	2677	4.24	3.38	19703.2	0.02887	0.06039	0.08928
			0			0			0.0			
65*****	AN/APX76( )(V) INTERROGATOR SET	171.09	3063	765.75	200.10	2619	3.12	1.99	14055.3	0.03554	0.02137	0.05692
66*****	EMERGENCY RADIO SYSTEMS	324.09	1617	404.25	374.06	1401	3.24	1.25	4739.0	0.01349	0.00346	0.01693
67*****	COM/NAV/IFF INTEGRATED PACKAGE SYSTEMS	53.45	9805	2451.26	70.61	7422	4.14	2.15	47028.0	0.10205	0.11671	0.21876
71*****	RADIO NAVIGATION SYSTEMS	154.86	3384	846.00	195.76	2677	4.21	2.16	16851.8	0.04300	0.02693	0.06996
72*****	RADAR NAVIGATION SYSTEMS	86.32	6071	1517.75	111.05	4719	4.39	2.44	24698.9	0.06564	0.04740	0.11303
73*****	AN/ASN130( ) INERTIAL NAVIGATION SET	45.77	11449	2862.24	59.61	8792	4.81	2.65	65869.8	0.13582	0.18667	0.32250
74*****	WEAPONS CONTROL SYSTEMS	6.07	86387	21596.84	7.87	66630	6.45	3.01	516398.0	1.04951	1.61224	2.66174
75*****	WEAPON DELIVERY	20.70	25315	6328.86	32.71	16023	4.70	1.26	155313.6	0.65543	0.17569	0.83109
76*****	COUNTERMEASURES SYSTEMS	20.55	25497	6374.23	25.46	20583	4.74	3.01	146249.4	0.32057	0.32619	0.64681
77*****	PHOTOGRAPHIC/RECONNAISSANCE SYSTEMS	50.47	10384	2596.01	71.89	7290	3.57	1.55	29464.4	0.09520	0.03118	0.12637
81*****	AIRBORNE GUIDED WEAPONS	262030.00	2	0.50	262030.00	2	3.23	0.81	5.7	0.00005	0.00000	0.00005
83*****	AIRBORNE EXPENDABLE ORDNANCE	65507.50	7	1.75	65507.50	7	3.15	0.76	24.4	0.00018	0.00000	0.00018
91*****	EMERGENCY EQUIPMENT	1050.22	499	124.75	1172.39	447	1.57	1.42	1405.7	0.00266	0.00119	0.00385
96*****	PERSONNEL EQUIPMENT	2802.46	187	46.75	3195.49	164	2.69	1.41	442.1	0.00086	0.00034	0.00121
97*****	EXPLOSIVE DEVICES	588.17	891	222.75	681.48	769	5.31	1.73	24277.7	0.10874	0.00021	0.10895
	ALL ($)	1.00	524745	131186.21	1.19	440884	6.50	2.58	4545580.4	16.72476	5.13268	21.81220

NALDA Baseline Spreadsheet.

This reduced the number of line items to 2,700. The data was then sub-divided into two-digit WUC system levels. These subdivisions totaled 39 two-digit WUC categories. The data in the MFHBF and FAILURES columns were then totaled for each two-digit WUC category. This worksheet also contained formulas that calculated the two-digit MFHBF and overall MFHBF by dividing the total number of flight hours (524,060) by the number of failures for each two-digit WUC as well as the totals of the MFHBF and FAILURE columns. The third worksheet "UCAV Comp" was developed to show the systems that would be eliminated in a UCAV. The MFHBF and FAILURE columns were then recalculated for each two-digit WUC. The total flight hours (524,060) was the divided by the resulting numbers in the two-digit WUC FAILURE column to calculate a UCAV MFHBF for each of the two-digit WUC systems and overall total MFHBF.

Fiscal Year	Aircraft Type/Model/Series	Element Number	Element Description	Then Year Dollars ($K)	FY 00 Dollars ($K)
1988	F/A-18C	1.1.1	Organizational Military Personnel Costs	21472	31938
1988	F/A-18C	1.1.2	Organizational Civilian Personnel Costs	0	0
1988	F/A-18C	1.1.3	Organizational Contractor Personnel Costs	0	0
1988	F/A-18C	1.2.1	Temporary Additional Duty Costs	132	170
1988	F/A-18C	1.2.2	Training Expendable Stores Costs	1830	2254
1988	F/A-18C	1.2.3	Support Supplies Costs	1112	1436
1988	F/A-18C	1.2.4	AVDLR Costs Total Regular	3174	4274
1988	F/A-18C	1.2.4.1	AVDLR Costs	3174	4274
1988	F/A-18C	1.2.4.2	Commercial RoR Costs	0	0
1988	F/A-18C	1.2.5	Fuel Costs	4870	9529

Example of Partial Elements in the CAIG Cost Template.

The VAMOSC CAIG template data was downloaded from the VAMOSC [VAMOSC-CAIG, 2000] website and transferred into an Excel spreadsheet for analysis. A partial example of the template format is seen in the example above.

It was found that the CAIG templates varied in elemental format where some elements had been added and eliminated according to the FY that was being analyzed. The elements that were the same were grouped as such: FY1988-1991, FY1992-1993, FY1994-1997, FY1998-1999 and then FY2000.

After each FY element difference was separated, the element costs were then totaled by FY column in the *Total* row of the spreadsheet as seen in the example below, and then discounted using a 10 percent rate in the formula:

$$\text{Total FY \$}/(1+\text{Discount rate\%})^{\text{Year number}}$$

The *Total* row was then added to the *Discounted cost* row to derive the *Cumulative discounted cost* row.

Year number	1	2
Total ($)	$46,563,000.00	$141,932,000.00
Discounted cost	$42,330,000.00	$117,299,173.55
Cumulative discounted cost	$88,893,000.00	$259,231,173.55

Example of the Element Total, Discounted and Cumulative Discounted Costs.

The *Cumulative discounted cost* row for each FY column was then totaled to equal an overall FY1988-FY2000 total LCC that established the baseline for comparison against the parametric F/A-18C baseline spreadsheet and analogous comparison with the UCAV parametric analysis spreadsheets.

2.   Parametric Model

Once the Baseline for validation of the F/A-18C parametric baseline spreadsheet was established, the information from the NALDA MFHBF was input into the parametric model. An Aerospace Engineering student at the Naval Postgraduate School, for a Logistics Engineering course [Junge, 2000], developed the parametric model that was used in the analysis of LCC for the Sea Arrow UCAV component of the Crossbow force. This model had been originally used for the academic analysis of LCC for a Vertical takeoff and Landing Unmanned Aerial Vehicle (VTUAV). This model was made up of six worksheets that were labeled *User Inputs, Manning, Training, RDT&E, O&M,* and *Totals*. There are two additional worksheets that were in the model that were a summary graph and a Poisson table that is used in calculation of component sparing.

The User Inputs page was made up of the components: *General Inputs*, *Training Inputs*, *Operational Inputs*, *Manning Inputs*, *Maintenance/Equipment Inputs*, *RDT&E and Production Inputs*, and *Component Inputs*.

The General Inputs component contained the *Discount Rate* block that was used in the formulation of the present value (PV) calculations in Manning, Training, RDT&E, O&M, and Totals worksheets into the formula:

$$\text{Total \$}*(1+\text{InflationRate})^{\text{number of Years}} / (1+(\text{DiscRate}+\text{InflateRate}))^{\text{number of Years}}$$

The Inflation Rate was an input to Inflation Rate formula:

$$\text{Total \$}*(1+\text{InflationRate})^{\text{number of Years}}$$

This formula was contained in the Manning, Training, RDT&E, O&M, and Totals worksheets. The inflation rate was assumed to be two percent. The *Attrition Rate* block was applied to the Training worksheet in the Excel formula:

If the number of squadrons present year is less than the number of squadrons past year, or the BTWEUAV (Basic Training Weeks Enlisted UAV then the number will equal zero, If not, the systems per squadron*the number of enlisted in the detachment *number of squadrons standing up)+(Attrition Rate*systems per squadron * the number of enlisted in the detachment * number of squadrons present year (rounded up to the nearest whole number.

This formula represented how the number of training program attritions for Officer, Chief Petty Officer (CPO) and Enlisted (E) pay grades One through Six were calculated. This attrition rate is based on the assumption that not all of the students in the training pipeline will complete the curriculum for various reasons. The attrition rate was assumed to be two percent.

The *Peacetime and Contingency Attrition Rates and Contingency Chance* blocks were used in the calculations in the *RDTE* worksheet that accounted for the losses of aircraft given the chances of the occurrence of a contingency operation. The Peacetime

and Contingency Rates were the attrition rates for the UCAV given a peacetime or Contingency scenario. It is assumed peacetime and contingency attrition rates in a minimum/maximum/delta format to be a peacetime rate of one percent/three percent/two percent and Contingency attrition rate to be five percent/ten percent/five percent respectively. The chance of the occurrence of a contingency was assumed to be 10 percent.

The *number of squadrons* provides data input to the number of I-Levels per squadron calculation in the User Inputs page, the transportation cost formula in the O&M worksheet, RDTE worksheet in the number of I-levels online row and the Totals worksheet into the *total systems built* calculation. The number of squadrons was assumed to be 30 for the F/A-18C parametric model. The *number of systems per squadron* was assumed to be "one" with 12 aircraft in a system.

Officer, CPO and E1-E6 salaries were based on Military Cost handbook figures [Price, Waterhouse, Coopers, 2001]. The Officer salary figure was calculated as an average of the O-3, O-4 and O-5 pay grades. The CPO salary was calculated as an average of E-7, E8 and E-9 and the Enlisted salary was calculated as an average of E1 – E6 pay grades.

The *life years of the program* was assumed to be 20 years. This was based on projected average life of an F/A-18C in the fleet.

a. Training Costs

Training costs were derived from data received from the Naval Education & Training Professional Development & Technology Center (NETPDTC) Pensacola, FL [Smith, 2001]. The subsequent average of Basic Training Costs and Advanced or "A-School" training costs were used as inputs for Basic and Advanced Air Vehicle (AV), I-Level Basic and Advanced and the Squadron Headquarters (HQ) Basic and Advanced Training blocks of the User Inputs worksheet.

The length of time for training was given in number of weeks required. The Officer training length of time was assumed to be a 50-week length of time for entry-level pilot training, and 50 weeks for advanced pilot training given an uninterrupted

pipeline. I-level Officer Training was assumed to be 10 weeks, which is currently the length of time for Aviation Maintenance Duty Officer Training. It was assumed that the Squadron HQ Officer required no training. The CPO Basic AV training was assumed to be 1 week for CPO indoctrination and no follow on training for an advanced AV level of expertise. I-level CPO and Squadron HQ CPO was assumed to be the same as Basic and Advanced AV CPO training lengths of time. The E1-E6 Basic AV training was based on a 10-week basic training syllabus and the Advanced AV training was based on an average of 3 weeks for A-school training. I-level Basic and Advanced and Squadron HQ Basic and Advanced were assumed to be the same lengths of time as the Basic and Advanced AV.

b. Operational Inputs

Operational Inputs included the Petroleum/Oil and Lubrication (POL) Costs per flight hour, Ground Equipment (UCAV only), AV flying hours per vehicle input on a per month basis and Auto Land and Launch per recovery hours (UCAV only). The Ground Control Equipment (GCE) Hours was assumed to be not applicable to the F/A-18C parametric model, however in the UCAV parametric model, these hours were assumed to be twice that of the air vehicle for the reason that training will be conducted on the GCE as well. The POL Costs per flight hour were based on VAMOSC data where the annual cost of fuel for FY2000 was divided by the number of total F/A-18C flight hours for that year. The Auto Land and Launch per recovery hours were assumed to be 90 percent of the total flight hours with the remaining 10 percent being pilot guided hours.

c. Manning Inputs

The manning numbers for the Detachment or Squadron F/A-18C baseline system was taken from current Navy squadron activity manning documents. The 25 Officers included 18 pilots and seven ground officers. The CPO manning includes all CPOs necessary for work center manning as well as a day and night shift in maintenance control. E1-E6 manning is based on all work centers in a standard F/A-18C squadron. The I-level manning was based on rough estimates of current Carrier Aircraft Intermediate Maintenance Department manning levels [Smith, 2001]. The Squadron HQ consists of a typical composition of an F/A-18C Strike Fighter Wing Staff. The UCAV

manning levels remained in the same three categories where the numbers of personnel assigned to the Detachment and Squadron HQ was based on figures from the Navy's UCAV program office.

d. *Maintenance and Equipment Inputs*

This section of the model was dedicated to the number of Air Vehicles in the system where the number of system is assumed to be only one per squadron. The Air Vehicle Unit Costs for the F/A-18C were based on figures presented in the Navy Fact File put out by Chief of Information (CHINFO) for the Navy [Chief of Naval Information, 2001]. The cost for the UCAV was based on data from a Naval Postgraduate School Aerospace Engineering Sea Arrow design team model.

Ground Equipment cost was assumed to be similar to the cost of the automated test equipment cost of $2.4M in the UCAV model only. The complete cost of test equipment at the I-level was unable to be determined from all of the data sources that were queried. Only the cost of the Consolidated Automated Support System (CASS) electronic test set could be determined based on cost data from the Military Cost Handbook. The remaining cost of I-level test equipment was assumed to be $7.6M for a total Test Equipment cost of $10M.

The Critical and Non-critical protection levels translate to the percentage of sparing levels for critical and non-critical systems within the Air Vehicle. Turn-Around-Times (TAT) for the I-level is based NALDA data from CY00-01. The I-level TAT is the average of all CV AIMD's from July of 2000 to July of 2001 with a low of 8 Days and a high 60 Days. The Depot Level (D-level) TAT is based on practical experience for the average F/A-18C Air Vehicle to go through the Depot at Naval Aviation Depot North Island. The number of I-levels is based on the assumption that there are 12 AIMD's aboard 12 Aircraft Carriers and one F/A-18C I-level per coast for a total of 14. The number of I-levels per squadron is simply based on a formula that divides the total number of I-levels by the number of squadrons.

The ratio of failures that were repaired at the I-level and the number of failures that were repaired at the D-level was based on information found in Blanchard's Logistics Engineering and Management [Blanchard, 1992]. The number of maintenance

actions split between the I-level and D-level to be 20 percent and 80 percent. The spare level factor on a per day basis was calculated based on the TAT of the I-level multiplied by the percentage of repairs at the I-level plus the TAT at the D-level multiplied by the percentage of repairs at the D-level all divided by 30 days in a month. The systems per I-level were calculated by dividing the number of systems per squadron by the number of I-levels per squadron.

There is assumed to be no I-level activation costs as the I-levels are already in operation at the time of Air Vehicle manufacture. The I-level cost per year is based on VAMOSC an average from FY88-00 of F/A-18C template element 2.0. Transportation and shipment cost was assumed to be $30.00 per part or unit.

e. *RDTE and Production Inputs*

Production Line Open Costs were assumed to be $25M. The RDTE over four years was based on facts from the Data Search Associates US Weapons Systems Costs 2000. The production line was assumed to be open for 10 years which was the actual number for the F/A-18C Hornet from 1988-1998. The first year of production was assumed to be in year four of the program with the first four years dedicated to RDTE. The system availability percentage was based on 2000 Commander Naval Forces Atlantic (COMNAVAIRLANT) readiness targets.

f. *Component Inputs*

The Component Inputs were comprised of the Reliability Factors and The Work Unit Codes (WUC) of the Aircraft Components. The original NALDA 5 digit WUC's were combined to a two-digit WUC system structure. The Reliability Factors were percentage MTBF increases that were applied to the WUC MTBF rates across the entire spectrum of components or systems that exist in the model. This feature enabled the user to perform broad sensitivity analyses of the LCC with the changes in the MTBF's. The table also computed the failure rate or λ of the component by using the equation:

$$\lambda \qquad = 1/\text{MTBF}$$

The table listed and labeled components as "Critical" or "Non-critical" components and are assigned a percentage from the Maintenance Equipment Input section of the worksheet. The last column on the Component Inputs was where the unit cost of the component was placed. This cost was derived as either the actual unit cost of the two-digit WUC or an average of the two-digit WUC component Aviation Depot Level Repairable (AVDLR) cost.

B.   DATA

In order to develop the parametric model for comparison of the Sea Arrow UCAV against the baseline F/A-18C system changes were made to the User Inputs worksheet. Parametric model descriptions and worksheet relationships were placed in appendices.

In the General Inputs section the numbers of squadrons increased from 30 squadrons to 60. This was based on outfitting (10 AC/Sqdn) on every Sea Archer (40x10ac/sqdn = 400AC); outfit East and West Cost FRS' (20AC-10 ac per FRS). Salaries stayed the same throughout the cost comparison. Additionally, each worksheet was changed in the *Number of Squadrons standing up* row to reflect 6 squadrons standing up each year from 2004 to 2013 for a total of 10 years.

The Training Section of the User Inputs was changed as Basic UAV changed to a 12-week training cycle (based on UCAV-N program data) from a 50-week cycle for Officers (pilot). CPO training changed from increased by weeks and Basic E1-6 training increased by two weeks. I-level and Squadron HQ training stayed the same.

Advanced Officer training stayed at 12 weeks for advanced pilot training and Crew Chief training CPO decreased to a 10 week training cycle in the advanced category. E1-6 training was increased by 7 weeks if they were scheduled to be a Crew Chief candidate. I-level and Squadron HQ stayed the same for training.

1.   Operational Costs

Fuel costs decreased from $723.30 to $136.95. This number was derived from the total lifetime fuel cost per air vehicle divided by the total number of hours over the lifetime of an AV. Ammunition costs were not considered as a portion of this parametric LCC evaluation.

Hours per month on the AV changed from 29.27 hours to 10 hours per month. Hours were reduced because more simulation time was assumed to take place during training when the squadron was in the Inter Deployment Training Cycle (IDTC). This data was based on the assumptions of the Aerospace Engineering team from NPS.

Ground Control Equipment (GCE) hours doubled that of the AV because it was assumed that GCE was used as a trainer as well for actual missions.

It was assumed that the Auto Launch and Recovery System (ALRS) was used 100 percent of the time afloat while that ALRS system will be used 80 percent ashore.

2. Manning Inputs

The number of Detachment officers decreased from 25 to 4, number of CPO's decreased from 16 to 8 and the number of E1-6 decreased from 182 to 134. These decreases were based on notional manning levels stated in UCAV-N data [Defense Advanced Research Projects Agency, 2001] with total detachment manning levels of 804 divided by 6 squadrons. The I-level remained static, however the squadron HQ decreased from 10 to 8 Officers, 20 down to 6 CPO's and from 10 down to 4 E1-6.

3. Maintenance and Equipment Inputs

Twelve AV's per squadron changed to 10 AV's per squadron for the Sea Arrow UCAV. The cost of the UCAV was based on Aerospace Engineering calculations that were made during the design of the Sea Arrow. The cost decreased from $29M per AV down to $9M per AV. Ground Equipment cost was added at a level of $2.4 M per GCE unit. I-level test equipment costs remained the same as the number of I-levels remained static.

Critical and Non-Critical protection levels remained the same. Even with the introduction of autonomic logistics and streamlined data flow, the desired spare protection level remained unchanged. The Turn Around Time (TAT) for the I-level decreased from 30 to 9 days; the Depot level TAT decreased from 120 to 90 days. These TAT decreases were driven by the assumption that the autonomic system was able to fault isolate earlier in the troubleshooting and repair cycle. This earlier isolation decreased the number of days spent trying to find the problem in a Weapons Replaceable Assembly (WRA) at the Intermediate Level. The number of I-levels, the number of

failures repaired at I and D level percentages, the operating cost per year of the I-level and the transportation cost all remained static.

4. RDT&E and Production Inputs

The production line open costs decreased from $25M to $10M; the RDT&E costs increased over all four years by varied amounts due to the new technologies that are being researched and developed for Unmanned Combat Aerial Vehicles (UCAV) and Tactical Unmanned Aerial Vehicles (UAV's). It was assumed that the production line was open for 10 years and made production runs of 600 UCAV's. This data was taken from Aerospace Engineering analysis. The UCAV system operational availability of 90 percent was based on the numbers proposed by UCAV-N supportability estimations.

5. Component Inputs

All of the component groupings were taken from the baseline system of the F/A-18C and improved by 20 percent. The same components were then analyzed at a 50 percent improvement. For the third trial, only the two lowest MTBF categories of Airframe and Flight Control Systems and Radar-Navigation and Weapons systems were improved by 50 percent and then the results were calculated.

C. ANALYSIS

The User Input and changes to worksheet data that was altered in order to provide an analogy between the F/A-18C and the Sea Arrow reduced many cost areas of the parametric LCC model. The analysis using the parametric model was conducted by inserting the UCAV data at the points discussed in the Data section into the established F/A-18C model. In the parametric model for the F/A-18C, the first data inputs from the original program data sources resulted in an overall LCC of $20.7B. Once the changes were made, the LCC of the Sea Arrow was found to be $13B, a decrease in the overall LCC of $7.7B. This analysis stepped through the changes made to the F/A-18C parametric model so that it accurately reflected the notional Sea Arrow UCAV. After all the changes had been made in the parametric F/A-18C model to reflect UCAV data, the Totals worksheets for both models were analyzed to determine which overall NPV areas were decreased and which cost areas had increased and why. It was found that changes in the overall LCC reflected the increase or decrease in the cost area (i.e.: manning,

training, etc). The last section of the analysis for each worksheet displayed what the specific cost area differences were between the UCAV and the F/A-18C.

Manpower reductions at the Organizational Level and Squadron HQ level resulted in an overall LCC increased despite the reduction in the number of squadron personnel required for the UCAV. The cost increase was $315M over the entire LCC. The reduction of 32 O-level (squadron personnel) and 22 Squadron HQ personnel in the UCAV model had a noteworthy impact as the cost per squadron was decreased with the changes in the number of weeks required for training. The reduction in manpower is typically one of the largest cost savings initiatives in any program as it is one of the top cost drivers. In the UCAV model, the costs in comparison to the F/A-18C decreased on a per squadron basis by 45 percent. This decrease occurred despite the addition of 30 UCAV squadrons.

The number of weeks required for training was decreased and the net result was a LCC cost increase because of the additional squadrons. The additions drove an $11M LCC category increase when transitioned from the F/A-18C to the UCAV model. The minimal cost increase with the reduction in the number of training weeks required for an unmanned system despite the additional manning was noteworthy. The reasons for these increases were simply due to the fact that the overall number of personnel had increased with the addition of 30 squadrons. Manpower and the training required are "cost static" in nature, meaning the only way to reduce costs in these areas is to reduce the amount of manpower and thereby eliminate subsequent training requirements.

The reduction in Production line open costs combined with the increase in RDTE costs over four years resulted in a net decrease of $4.58B despite the increase in the number of AV's produced. The resultant savings of $15M was due to reducing Production line open costs and the cost of the UCAV was $20M per unit less. This savings came as a result of the Production line open costs having been reduced by $15M and the cost of the UCAV was $20M less per copy to produce. The production line open costs were reduced due to the modular design improvements of the Sea Arrow UCAV as well as the reduction in production space requirements for an aircraft 1/3 the size of the F/A-18C Hornet. RDTE costs over the four years, however, were increased for the

unmanned AV because of the technology requirements of the GCE, the unproven technologies of the unmanned realm of aircraft and the research necessary for their integration into carrier operations.

In changing the number of squadrons in the General Inputs section, *Number of AV's per system* and *AV unit cost* data from the Maintenance/Equipment input section of the model had to be changed simultaneously. When these changes were made the LCC appeared to have increased. The reason for this, despite the cost reduction of the AV to $9.4M apiece, was that the number of total aircraft produced and maintained jumped from 360 to 600. POL or Fuel costs were then changed to reflect the cost per hour of the notional Sea Arrow. This change reduced the overall LCC. This cost reduction demonstrated the operational LCC savings of a smaller, more fuel-efficient AV.

With the advent of the UCAV, however, the Ground Control Equipment (GCE) inputs were introduced into the analysis. The hours per month usage on the GCE produced no change to the overall LCC, as the operating costs of the GCE are negligible. The Auto Launch and Recovery hours also increased due to the introduction of the unmanned aspect, but again this added nothing to the overall LCC increase. On the other hand, the purchase cost of the GCE must be considered. This purchase of GCE increased the LCC from $25.82B to $25.88B, an increase of $66M. This increase was inevitable due to the necessity of having some means to control the AV. Although the overall costs increased, the actual cost of pilot training over the entire LCC remains exponentially higher than the cost of the unmanned pilot training and GCE required for an unmanned system.

The Operating hours of the UCAV, when reduced to 10 hours per month from the 29.97 hours per month of the F/A-18C, resulted in another significant cost savings. This reduction in operating expense due to less flight hours drove the sparing level that was determined with the number of flight hours per month. Flying the aircraft less for training and strictly for operational purposes produces LCC savings on several levels, most notably, in spare components and fuel costs. However an unrealized benefit of reduced flight hours in this spreadsheet was the LCC savings as a result of the reduction

in wear and tear of frequent carrier based take-offs and landings. Improvements in target system availability had no bearing on LCC even though the target increased from 75% to 90% availability.

The data for TAT with regards to the I and D levels was reduced in the Sea Arrow as previously explained with the assumption of Autonomic Logistics and Prognostic and Health monitoring systems. This reduction in I-level TAT produced an overall reduction in LCC down to $13.86B a total of $2B. The reduction was driven by the fact that with a decrease in TAT, a lesser number of spares were required for system support. Also, a decrease in TAT requires less spares to support a system. When the D-level TAT was decreased from 120 to 90 days, the overall LCC was decreased again. The radical LCC cost reduction due to the TAT reductions by 70 percent at the I-level and 25 percent at the Depot level, highlighted the importance of the development of autonomic troubleshooting and aircraft health and monitoring technology, and the importance of looking for ways to reduce logistics delays.

Through the development and implementation of these technologies, significant savings over the entire life cycle of a system could be realized. Studies performed by Northrop Grumman for the Joint Strike Fighter (JSF) Program underscored the importance of Autonomic and Prognostic systems.   During their analysis of troubleshooting hours for Cannot Duplicate (CND) and Retest OK (RETOK) maintenance actions, it was found that there was a five fold improvement in heading off CND troubleshooting and the RETOK maintenance action was completely eliminated [Brown, 2001g].

The final section that changed the analogy in the parametric analysis was the improvement in the MTBF. The MTBF was assumed to have an improvement of 20 percent due to reliability improvements as a result of technology advances. The end result of this reliability improvement was a cost reduction of $13.02B. Given a 50 percent improvement across the entire component spectrum, the cost was reduced by $806M.   There are however significantly lower reliabilities that are noted in two component areas. The areas of the WUC 1* series for Airframe and Flight Control

Systems and WUC 7* series for Radar-Radar Navigation, and Weapons Systems had MTBF factor of 6.69 hours and 6.09 respectively. <u>With the 20 and 50 percent improvement in these two component areas alone, a $673M LCC reduction was realized.</u> This accentuates the importance of the pursuit of even seemingly minimal reliability improvements.

Operations and Maintenance costs proved to be the largest decrease in LCC during the analysis. The total category LCC savings of $5.5B was made possible by the reduction of fuel costs, flight hours per month coupled with across the board reliability improvements of the AV components.

A leading aviation industry firm supportability and sustainment engineer stated that the target for a UCAV concept should be 20 to 30 percent of the O&M cost of a baseline, real-world combat aircraft system. During normalization of the UCAV and F/A-18C parametric spreadsheets and subsequent sensitivity analysis, it was found that the actual per squadron O&M cost of the Sea Arrow was 27.5% of the per squadron O&M cost for the F/A-18C baseline. This was found to be within the recommended industry range of 20 to 30 percent for costing of a notional aircraft weapon system.

F/A-18c User Inputs and MTBF Inputs Example.

UCAV Life Cycle Cost (LCC) Analysis: User Inputs

General Inputs

Discount Rate	10%	
Inflation Rate	2%	
Attrition Rate	2%	
Peace Time Rate (Min/Max/Delta)	1%	3%	2%
Contingency Rate (Min/Max/Delta)	5%	10%	5%
Contingency Chance	10%	
Number of Squadrons	60	
Number of Systems/Squadron	1	
Officer Salary	$ 103,000.00	
CPO Salary	$ 68,000.00	
E-1 to E-6 Salary	$ 34,000.00	
Life Years of Program	20	

Training Inputs

Basic Training Costs	$ 2,620.00	
Advanced Maintenance Training Costs	$ 1,156.00	

	Weeks Required		
	Officer	CPO	E-1 to E-6
Basic AV	12	12	12
Advanced AV	12	10	10
I-Level Basic Maint. Training	10	1	10
I-Level Adv Maint. Training	0	0	8
Squadron HQ Basic Training	0	1	10
Squadron HQ Adv Training	0	0	8

Operational Inputs

POL Cost/Flt Hour	$ 135.95	

	Month	Year
Ground Equip Hours	20	240
AV Flying Hours/Vehicle	10	120
Autol and 8 Launch/Rec Hours	8	100

Manning Inputs

	Det.	I-Level	Squadron HQ
Officers	4	20	0
CPOs	0	40	6
E-1 to E-6	178	500	4
	190	560	18

Maintenance/Equipment Inputs

Number of AVs per System	10
AV Unit Cost	$ 9,400,000.00
Ground Control Equip Cost	$ 2,350,000.00
Test Equipment (I-Level) Cost	$ 10,000,000.00
Critical Protection Level	0.85
Non-Critical Protection Level	0.75
TAT (days) = I-Level	0
TAT (days) = D-Level	90
Number of I-Levels	14
I-Levels/Squadron	0.233333333
Failures Repaired At I-Level	80%
Failures Repaired At D-Level	20%
Spare Level Factor	0.0400
Systems/I-Level	4.285/14.286
I-Level Activation Cost	$
I-Level Operating Cost/yr	$ 47,200,000.00
Transportation $/Shipment	$ 50.00 from detachment to I-level

RDTE & Production Inputs

Production Line Open Costs	$ 10,000,000.00
RDTE Year 1	$ 53,071,000.00
RDTE Year 2	$ 56,189,000.00
RDTE Year 3	$ 43,087,000.00
RDTE Year 4	$ 29,427,000.00
Number of Years Line Open	10
First Year of Production	4
System Available %	90%

FA-18C Life Cycle Cost (LCC) Analysis: MTBF Inputs

Component Inputs

Reliability Factors

MTBF Factor I	1.2
MTBF Factor II	1.2

Code Name (WUC)	Name	MTBF Code Name		MTBF	Failure Rate (λ)	Critical/NonCritical	PL		Unit Cost
Maintenance Inspections (03)	MINSP	MTBFMINSP	07343	104011.6	0.000010	NonCritical	0.75	$	8,500
Corrosion Prevention (04)	CP	MTBFCP	262030	314436	0.000003	NonCritical	0.75	$	1,144
General Functions (06)	GF	MTBFGF	50027	50002.4	0.000027	NonCritical	0.75	$	1,340
Non Aeronautical Work (09)	NAW	MTBFNAW	8734	10490.8	0.000095	NonCritical	0.75	$	187,160
Airframe and Flight Ctrl Sys (1")	AF-FCS	MTBFAFFCS	6.69	8.028	0.124564	Critical	0.95	$	4,798,612
Engine/APU (2")	EAPU	MTBFEAPU	48.92	58.704	0.017035	Critical	0.95	$	3,305,031
Utility Systems (4")	UTIL	MTBFUTIL	26.41	31.692	0.031554	Critical	0.95	$	2,403,147
Instrumentation (5")	INSTR	MTBFINSTR	44.44	48.778	0.020498	Critical	0.9%	$	1,482,658
Comm-Nav-IFF (6")	COMNAVIFF	MTBFCNAVIFF	53.45	64.14	0.015591	Critical	0.95	$	3,618,474
Radio-Radar Nav/Weps CS (7")	RNAVWCS	MTBFRNAVWCS	6.09	7.308	0.136836	Critical	0.95	$	1,595,278
Airborne Expendable Ordnance (8")	AEO	MTBFAEO	65507	78608.4	0.000013	Critical	0.85	$	1,592
Ground Control Equipment	GCE	MTBFGCE	269.5	323.4	0.003092	Critical	0.85	$	4,000,000
Ground Data Terminal	GDT	MTBFGDT	295.9	355.08	0.002816	Critical	0.85	$	1,200,000
Explosive Devices (97)	CADS	MTBFCADS	588.17	705.804	0.001417	Critical	0.85	$	3,290

LIFE CYCLE COSTS

$ 13,359,248,212

Red Numbers ⇒ Inputs
Blue Numbers ⇒ Computed

UCAV Parametric Model User Inputs and MTBF Inputs Example.

FA-18C Life Cycle Cost (LCC) Analysis: Manning

Req'd Manning Levels	Squadron	I-Level (1/sqdn)	HQ
Officer	25	20	10
CPO	16	40	20
Enlisted	182	500	10

	Salary/Individ	Squadron	Per I-Level	Squadron HQ
Officer	$ 103,000.00	$ 2,575,000	$ 2,060,000	$ 1,030,000
NCO	$ 68,000.00	$ 1,088,000	$ 2,720,000	$ 1,360,000
Enlisted	$ 34,000.00	$ 6,188,000	$ 17,000,000	$ 340,000
Total		$ 9,851,000	$ 21,780,000	$ 2,730,000

FY Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Year	1	2	3	4	5	6	7	8	9
Squadrons "Standing Up"	0	0	0	0	3	6	3	4	4
Squadrons "Decomming"	0	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	3	9	12	16	20
Number of I-Levels On Line	0	0	0	0	7	14	14	14	14
Number of New Systems	0	0	0	0	3	6	3	4	4
Total Number of Systems	0	0	0	0	3	9	12	16	20
Squadron	$ -	$ -	$ -	$ -	$ 29,553,000	$ 88,659,000	$ 118,212,000	$ 157,616,000	$ 197,020,000
I-Level	$ -	$ -	$ -	$ -	$152,460,000	$ 304,920,000	$ 304,920,000	$ 304,920,000	$ 304,920,000
Squadron HQ	$ -	$ -	$ -	$ -	$ 2,730,000	$ 2,730,000	$ 2,730,000	$ 2,730,000	$ 2,730,000
Total (Current $)	$ -	$ -	$ -	$ -	$184,743,000	$ 396,309,000	$ 425,862,000	$ 465,266,000	$ 504,670,000
Inflation (Then Year)	$ -	$ -	$ -	$ -	$203,971,200	$ 446,308,302	$ 489,181,576	$ 545,133,274	$ 603,127,367
PV (FY2000)	$ -	$ -	$ -	$ -	$115,738,737	$ 226,113,676	$ 221,280,902	$ 220,170,186	$ 217,493,775
NPV (FY2000)	$ 2,951,580,814								

F/A-18C Parametric Model Manning Worksheet Example.

Req'd Manning Levels	Squadron	I-Level (1/sqdn)	HQ
Officer	4	20	8
CPO	8	40	6
Enlisted	178	500	4

	Salary/Individ	Squadron	Per I-Level	Squadron HQ
Officer	$ 103,000.00	$ 412,000	$ 2,060,000	$ 824,000
NCO	$ 68,000.00	$ 544,000	$ 2,720,000	$ 408,000
Enlisted	$ 34,000.00	$ 6,052,000	$ 17,000,000	$ 136,000
Total		$ 7,008,000	$ 21,780,000	$ 1,368,000

FY Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Year	1	2	3	4	5	6	7	8	9
Squadrons "Standing Up"	0	0	0	0	6	6	6	6	6
Squadrons "Decomming"	0	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	6	12	18	24	30
Number of I-Levels On Line	0	0	0	0	7	14	14	14	14
Number of New Systems	0	0	0	0	6	6	6	6	6
Total Number of Systems	0	0	0	0	6	12	18	24	30
Squadron	$ -	$ -	$ -	$ -	$ 42,048,000	$ 84,096,000	$ 126,144,000	$ 168,192,000	$ 210,240,000
I-Level	$ -	$ -	$ -	$ -	$ 152,460,000	$ 304,920,000	$ 304,920,000	$ 304,920,000	$ 304,920,000
Squadron HQ	$ -	$ -	$ -	$ -	$ 1,368,000	$ 1,368,000	$ 1,368,000	$ 1,368,000	$ 1,368,000
Total (Current $)	$ -	$ -	$ -	$ -	$ 195,876,000	$ 390,384,000	$ 432,432,000	$ 474,480,000	$ 516,528,000
Inflation (Then Year)	$ -	$ -	$ -	$ -	$ 216,262,931	$ 439,635,790	$ 496,728,441	$ 555,928,943	$ 617,298,774
PV (FY2000)	$ -	$ -	$ -	$ -	$ 122,713,395	$ 222,733,173	$ 224,694,720	$ 224,530,376	$ 222,604,126
NPV (FY2000)	$ 3,266,024,878								

Cost per Squadron $54,433,747.97

% of F/A-18C Cost   55.3%

UCAV Parametric Model Manning Worksheet Example.

D.   DESCRIPTION OF THE MANNING WORKSHEET

This section of the parametric model focused on the total manpower costs for the Officer, CPO and Enlisted and the O, I and Squadron Headquarters levels. This cost worksheet was divided into four sections, the Required Manning Levels, Individual Salary calculations, FY Inputs section that was formatted by FY number and by corresponding program year number, and Totals for Squadron, I-level and Squadron Headquarters.

Required Manning Levels and inputs for the Salary per Individual section of the salary calculations were taken directly from the User Inputs Manning section and General Inputs Sections respectively. The salaries were then multiplied by the number of personnel at each of the Squadron, I-level, and Squadron Headquarters to provide a total manning cost per activity. This formula was as follows:

Salary Total = Number of applicable personnel *Salary of Applicable category

For example:

Salary Total = 16 Detachment CPO's * $68,000.00

The section FY Inputs Section allowed for the input of the number of squadrons standing up, the number of squadrons decommissioning, total number of squadrons, number of new systems, and total number of systems. These FY inputs were then referenced in the Manning LCC calculations over 20 years, the totals of the Squadron, I-level and Squadron HQ manning costs over 20 years. For example for a Squadron total:

Total Manning Cost = Total Squadron Salary * Number of Squadrons in that FY

Totals. The LCC calculations for each activity were then totaled in Current Year dollars, Then Year Inflation, and Present Value (PV). From the PV row of the worksheet, a Net Present Value (NPV) was calculated for the Manning worksheet and the subsequent total was then transferred to the Totals worksheet.

FA-18C Life Cycle Cost (LCC) Analysis: Training

Training Cost (Individual)	Basic UAV	Adv UAV	I-Level Basic	I-Level Adv	SQ HQ Basic	SQ HQ Adv
Officer	$ 131,450.00	$ 57,800.00	$ 26,290.00	$ -	$ -	$ -
CPO	$ 2,629.00	$ -	$ 2,629.00	$ -	$ 2,629.00	$ -
Enlisted	$ 26,290.00	$ 3,468.00	$ 26,290.00	$ 3,468.00	$ 26,290.00	$ 3,468.00

Personnel Requiring Training

FY Year	2000	2001	2002	2003	2004	2005	2006	2007
Year	1	2	3	4	5	6	7	8
Squadrons "Standing Up"	0	0	0	0	3	6	3	4
Squadrons "Decomming"	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	3	9	12	16
Number of I-Levels On Line	0	0	0	0	7	14	14	14
Number of New Systems	0	0	0	0	3	6	3	4
Total Number of Systems	0	0	0	0	3	9	12	16
Detachment Basic								
Officer	0	0	0	75	152	80	106	108
Chief Petty Officers	0	0	0	48	97	51	68	70
Junior Enlisted	0	0	0	546	1103	579	772	787
Detachment Advanced								
Officer	0	0	0	75	152	80	106	108
Chief Petty Officers	0	0	0	0	0	0	0	0
Junior Enlisted	0	0	0	546	1103	579	772	787
I-Level Basic								
Officer	0	0	0	28	57	30	40	41
Chief Petty Officers	0	0	0	56	114	60	80	81
Junior Enlisted	0	0	0	700	1414	742	990	1008
I-Level Advanced								
Officer	0	0	0	0	0	0	0	0
Chief Petty Officers	0	0	0	0	0	0	0	0
Junior Enlisted	0	0	0	700	1414	742	990	1008
Squadron HQ Basic								
Officer	0	0	0	0	0	0	0	0
Chief Petty Officers	0	0	0	60	122	64	85	87
Junior Enlisted	0	0	0	30	61	32	43	44
Squadron HQ Adv								
Officer	0	0	0	0	0	0	0	0
Chief Petty Officers	0	0	0	0	0	0	0	0
Junior Enlisted	0	0	0	30	61	32	43	44

F/A-18C Parametric Model Training Worksheet Example.

Funds Required for Training

FY Year	2000	2001	2002	2003	2004	2005	2006
Year	1	2	3	4	5	6	7
Detachment Basic							
Officer	$ -	$ -	$ -	$ 9,858,750.00	$ 19,980,400.00	$ 10,516,000.00	$ 13,933,700.00
Chief Petty Officers	$ -	$ -	$ -	$ 126,192.00	$ 255,013.00	$ 134,079.00	$ 178,772.00
Junior Enlisted	$ -	$ -	$ -	$ 14,354,340.00	$ 28,997,870.00	$ 15,221,910.00	$ 20,295,880.00
Detachment Advanced							
Officer	$ -	$ -	$ -	$ 4,335,000.00	$ 8,785,600.00	$ 4,624,000.00	$ 6,126,800.00
Chief Petty Officers							
Junior Enlisted							
I-level Basic							
Officer	$ -	$ -	$ -	$ 736,120.00	$ 1,498,530.00	$ 788,700.00	$ 1,051,600.00
Chief Petty Officers	$ -	$ -	$ -	$ 147,224.00	$ 299,706.00	$ 157,740.00	$ 210,320.00
Junior Enlisted	$ -	$ -	$ -	$ 18,403,000.00	$ 37,174,060.00	$ 19,507,180.00	$ 26,027,100.00
I-Level Advanced							
Officer	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Chief Petty Officers	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Junior Enlisted							
Squadron HQ Basic							
Officer	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Chief Petty Officers	$ -	$ -	$ -	$ 157,740.00	$ 320,738.00	$ 168,256.00	$ 223,465.00
Junior Enlisted	$ -	$ -	$ -	$ 788,700.00	$ 1,603,690.00	$ 841,280.00	$ 1,130,470.00
Squadron HQ Adv							
Officer	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Chief Petty Officers	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Junior Enlisted	$ -	$ -	$ -	$ 104,040.00	$ 211,548.00	$ 110,976.00	$ 149,124.00
Total (Current $)	$ -	$ -	$ -	$ 48,907,066.00	$ 98,915,607.00	$ 51,959,145.00	$ 69,178,107.00
Inflation (Then Year)	$ -	$ -	$ -	$ 52,938,581.09	$ 109,210,822.83	$ 58,514,436.44	$ 79,463,900.03
PV (FY 2000)	$ -	$ -	$ -	$ 33,643,425.33	$ 61,969,153.81	$ 29,645,234.54	$ 35,945,432.82
NPV	$ 289,922,564.20						

F/A-18C Parametric Model Training Worksheet Example (Page 2).

UCAV Life Cycle Cost (LCC) Analysis: Training

Training Cost (Individual)

Training Cost (Individual)	Basic UAV	Adv UAV	I-Level Basic	I-Level Adv	SQ HQ Basic	SQ HQ Adv
Officer	$ 31,548.00	$ 13,872.00	$ 26,290.00	$ -	$ -	$ -
CPO	$ 31,548.00	$ 11,560.00	$ 2,629.00	$ -	$ 2,629.00	$ -
Enlisted	$ 31,548.00	$ 11,560.00	$ 26,290.00	$ 9,248.00	$ 26,290.00	$ 9,248.00

Personnel Requiring Training

FY Year	2000	2001	2002	2003	2004	2005	2006	2007
Year	1	2	3	4	5	6	7	8
Squadrons "Standing Up"	0	0	0	0	6	6	6	6
Squadrons "Decomming"	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	6	12	18	24
Number of I-Levels On Line	0	0	0	0	7	14	14	14
Number of New Systems	0	0	0	0	6	6	6	6
Total Number of Systems	0	0	0	0	6	12	18	24
Detachment Basic								
Officer	0	0	0	24	25	25	26	26
Chief Petty Officers	0	0	0	48	49	50	51	52
Junior Enlisted	0	0	0	1068	1090	1111	1133	1154
Detachment Advanced								
Officer	0	0	0	24	25	25	26	26
Chief Petty Officers	0	0	0	48	49	50	51	52
Junior Enlisted	0	0	0	1068	1090	1111	1133	1154
I-Level Basic								
Officer	0	0	0	28	29	30	30	31
Chief Petty Officers	0	0	0	56	58	59	60	61
Junior Enlisted	0	0	0	700	714	728	742	756
I-Level Advanced								
Officer	0	0	0	0	0	0	0	0
Chief Petty Officers	0	0	0	0	0	0	0	0
Junior Enlisted	0	0	0	700	714	728	742	756
Squadron HQ Basic								
Officer	0	0	0	0	0	0	0	0
Chief Petty Officers	0	0	0	36	37	38	39	39
Junior Enlisted	0	0	0	24	25	25	26	26
Squadron HQ Adv								
Officer	0	0	0	0	0	0	0	0
Chief Petty Officers	0	0	0	0	0	0	0	0
Junior Enlisted	0	0	0	24	25	25	26	26

UCAV Parametric Model Training Worksheet Example.

Funds Required for Training								
FY Year	2000	2001	2002	2003	2004	2005	2006	2007
Year	1	2	3	4	5	6	7	8
Detachment Basic								
Officer	$ -	$ -	$ -	$ 757,152.00	$ 788,700.00	$ 788,700.00	$ 820,248.00	$ 820,248.00
Chief Petty Officers	$ -	$ -	$ -	$ 1,514,304.00	$ 1,545,852.00	$ 1,577,400.00	$ 1,608,948.00	$ 1,640,496.00
Junior Enlisted	$ -	$ -	$ -	$ 33,693,264.00	$ 34,387,320.00	$ 35,049,828.00	$ 35,743,884.00	$ 36,406,392.00
Detachment Advanced								
Officer	$ -	$ -	$ -	$ 332,928.00	$ 346,800.00	$ 346,800.00	$ 360,672.00	$ 360,672.00
Chief Petty Officers								
Junior Enlisted								
I-level Basic								
Officer	$ -	$ -	$ -	$ 736,120.00	$ 762,410.00	$ 788,700.00	$ 788,700.00	$ 814,990.00
Chief Petty Officers	$ -	$ -	$ -	$ 147,224.00	$ 152,482.00	$ 155,111.00	$ 157,740.00	$ 160,369.00
Junior Enlisted	$ -	$ -	$ -	$ 18,403,000.00	$ 18,771,060.00	$ 19,139,120.00	$ 19,507,180.00	$ 19,875,240.00
I-Level Advanced								
Officer	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Chief Petty Officers	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Junior Enlisted								
Squadron HQ Basic								
Officer	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Chief Petty Officers	$ -	$ -	$ -	$ 94,644.00	$ 97,273.00	$ 99,902.00	$ 102,531.00	$ 102,531.00
Junior Enlisted	$ -	$ -	$ -	$ 630,960.00	$ 657,250.00	$ 657,250.00	$ 683,540.00	$ 683,540.00
Squadron HQ Adv								
Officer	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Chief Petty Officers	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Junior Enlisted	$ -	$ -	$ -	$ 221,952.00	$ 231,200.00	$ 231,200.00	$ 240,448.00	$ 240,448.00
Total (Current $)	$ -	$ -	$ -	$ 56,309,596.00	$ 57,509,147.00	$ 58,602,811.00	$ 59,773,443.00	$ 60,864,478.00
Inflation (Then Year)	$ -	$ -	$ -	$ 60,951,317.63	$ 63,494,745.21	$ 65,996,283.41	$ 68,660,897.28	$ 71,312,436.62
PV (FY 2000)	$ -	$ -	$ -	$ 38,735,664.25	$ 36,028,623.63	$ 33,435,771.06	$ 31,058,703.01	$ 28,801,897.10
NPV	$ 301,565,018.91							

Cost Per Sqaudron	$ 5,026,083.65
% of F/A-18C cost	52.0%

UCAV Parametric Model Training Worksheet Example (Page 2).

E.   DESCRIPTION OF THE TRAINING WORKSHEET

This section of the parametric model focused on the total training costs for the Officer, CPO and Enlisted and the O, I and Squadron Headquarters levels. This cost worksheet was divided into three sections, the Training Cost of the individual, number of personnel that require training, and the funds required for training.

The Training cost per individual was determined for all levels of maintenance at the Officer, CPO and E1-E6 by the equation:

=Cost category of advanced or basic training*applicable number of weeks

For example:

Individual Cost = $2629.00 (cost of advanced training) * 50 weeks

Each of the inputs for this equation came from the User Inputs worksheet in the Training Inputs section.

The number of personnel requiring training was calculated from inputs from the section of the worksheet that details FY Inputs section and is formatted by FY number and by corresponding program year number. This section allows for the input of the number of squadrons standing up, the number of squadrons decommissioning, total number of squadrons, number of new systems, and total number of systems. Each of these sections is input according to the FY and corresponding year in which the event took place. After this information is placed into the worksheet, the Detachment, I-level and Squadron Headquarters costs for all categories of Officer, CPO and Enlisted are all calculated using the Excel formula:

**=IF(OR(F16<E16,BTWOUAV=0),"0",CEILING((sysPERsquad*DetO*G14)+
(AttriteRate*sysPERsquad*DetO*F16),1))**

In plain language:

If the number of squadrons in the present year was less than the previous year or the Basic Training weeks equal zero, then the number of personnel requiring training was zero. If not, then the systems per squadron was multiplied by the number of applicable personnel (O, CPO or E) and the number of squadrons standing up. All this was added to the total of the attrition rate from the User Inputs page multiplied by the systems per squadron, the number of applicable personnel (O, CPO or E) and the number of squadrons for that year.

The Funds Required for Training section of the Training worksheet was formatted the same as Figure (x) in this appendix. Each of the cells for the categories were calculated by using the formula:

Funds Required = Personnel requiring training * Cost of training for the category

For Example:

Funds Required = 75 Officers * $131,450 (Basic Officer Training Cost)

The Training costs were then totaled in the Totals section of the spreadsheet and then the Then Year Inflation, PV (FY2000), and a total NPV of the Training costs was added from the PV row and sent as an input to the Totals worksheet.

FA-18C Life Cycle Cost (LCC) Analysis:	RDT&E and Production							
FY Year	2000	2001	2002	2003	2004	2005	2006	2007
Year	1	2	3	4	5	6	7	8
Squadrons "Standing Up"	0	0	0	0	3	0	3	4
Squadrons "Decomming"	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	3	9	12	16
Number of I-Levels On Line	0	0	0	0	7	14	14	14
Number Systems Produced	0	0	0	3	6	3	4	4
Number of New Systems	0	0	0	0	3	0	3	4
Total Number of Systems	0	0	0	0	3	9	12	16
Total Number of AVs Fielded	0	0	0	0	36	108	144	192
UAV Attrition Information								
Contigency Theatre I -- WestPac and IO								
Contigency – Yes(1) or No(0)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
UAV Attrition Rate	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673
Number of UAVs in Operating in Theatre	0	0	0	0	18	54	72	96
Attrition AVs	0	0	0	0	2	4	5	7
Contigency Theatre II -- Atlantic & Mediterranean								
Contigency ~ Yes(1) or No(0)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
UAV Attrition Rate	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673
Number of UAVs in Operating in Theatre	0	0	0	0	18	54	72	96
Attrition AVs	0	0	0	0	2	4	5	7
Peccrent of AVs in "Available" for Service	0%	0%	0%	0%	256%	150%	137%	127%
Total Number of Attrition AVs	0	0	0	0	4	8	10	14
Total Number of Attrition Avs Produced	0	0	0	58	58	58	58	58
Total Number of AVs Produced	0	0	0	94	130	94	106	106
Production Line Open Costs	$ -	$ -	$ -	$ 25,000,000.00	$ 25,000,000.00	$ 25,000,000.00	$ 25,000,000.00	$ 25,000,000.00
Ground Equipment Information								
Number of Ground Control Equipment Produced	0	0	0	3	6	3	4	4
Number of Ground Control Equipment Fielded								
Number of Test Equipment Produced/Installed	0	0	0	7	7	0	0	0
Development Costs	$ 30,000,000.00	$ 11,800,000.00	$ 10,100,000.00	$ 33,300,000.00	$ -	$ -	$ -	$ -
Production Costs								
AV Systems	$ -	$ -	$ -	$ 2,726,000,000.00	$ 3,770,000,000.00	$ 2,726,000,000.00	$ 3,074,000,000.00	$ 3,074,000,000.00
Ground Control Equipment Units	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Test Equipment Units (including installation)	$ -	$ -	$ -	$ 70,000,000.00	$ 70,000,000.00	$ -	$ -	$ -
Total Production Costs	$ -	$ -	$ -	$ 2,796,000,000.00	$ 3,840,000,000.00	$ 2,726,000,000.00	$ 3,074,000,000.00	$ 3,074,000,000.00
Total RDTE & Production Costs (Current Year $)	$ 30,000,000.00	$ 11,800,000.00	$ 10,100,000.00	$ 2,829,300,000.00	$ 3,840,000,000.00	$ 2,726,000,000.00	$ 3,074,000,000.00	$ 3,074,000,000.00
Inflation (Then Year)	$ 30,000,000.00	$ 11,800,000.00	$ 10,100,000.00	$ 2,829,300,000.00	$ 3,840,000,000.00	$ 2,726,000,000.00	$ 3,074,000,000.00	$ 3,074,000,000.00
PV(FY2000)	$ 27,272,727.27	$ 9,752,066.12	$ 7,588,279.49	$ 1,932,449,969.26	$ 2,384,337,880.55	$ 1,538,755,933.33	$ 1,577,448,055.44	$ 1,434,043,686.76
Cumulative Present Day ~ No Inflation	$ 30,000,000.00	$ 41,800,000.00	$ 51,900,000.00	$ 2,881,200,000.00	$ 6,721,200,000.00	$ 9,447,200,000.00	$ 12,521,200,000.00	$ 15,595,200,000.00
Cumulative Present Day ~ Inflation	$ 30,000,000.00	$ 41,800,000.00	$ 51,900,000.00	$ 2,881,200,000.00	$ 6,721,200,000.00	$ 9,447,200,000.00	$ 12,521,200,000.00	$ 15,595,200,000.00
Cumulative PV (FY2000)	$ 27,272,727.27	$ 37,024,793.39	$ 44,613,072.88	$ 1,977,063,042.14	$ 4,361,400,922.69	$ 5,900,156,856.02	$ 7,477,604,911.46	$ 8,911,648,598.22
Total Development and Production Costs (FY2000)	$ 30,000,000	$ 11,800,000	$ 10,100,000	$ 2,829,300,000	$ 3,840,000,000	$ 2,726,000,000	$ 3,074,000,000	$ 3,074,000,000
Cumulative Total (FY2000)	$ 30,000,000	$ 41,800,000	$ 51,900,000	$ 2,881,200,000	$ 6,721,200,000	$ 9,447,200,000	$ 12,521,200,000	$ 15,595,200,000
Cumulative Inflated Total (Then Year)	$ 30,000,000	$ 41,800,000	$ 51,900,000	$ 2,881,200,000	$ 6,721,200,000	$ 9,447,200,000	$ 12,521,200,000	$ 15,595,200,000
Inflation (Then Year)	$ 30,000,000	$ 11,800,000	$ 10,100,000	$ 2,829,300,000	$ 3,840,000,000	$ 2,726,000,000	$ 3,074,000,000	$ 3,074,000,000
PV (FY2000)	$ 27,272,727	$ 9,752,066	$ 7,588,279	$ 1,932,449,969	$ 2,384,337,881	$ 1,538,755,933	$ 1,577,448,055	$ 1,434,043,687
Cumulative PV (FY2000)	$ 27,272,727	$ 37,024,793	$ 44,613,073	$ 1,977,063,042	$ 4,361,400,923	$ 5,900,156,856	$ 7,477,604,911	$ 8,911,648,598
NPV (FY2000)	$ 13,239,491,364							
NPV (FY2000)	$ 13,239,491,364							

F/A-18C Parametric Model RDT&E Worksheet Exam.

UCAV Life Cycle Cost (LCC) Analysis:	RDT&E and Production						

FY Year	2000	2001	2002	2003	2004	2005	2006	2007
Year	1	2	3	4	5	6	7	8
Squadrons "Standing Up"	0	0	0	0	6	6	6	6
Squadrons "Decomming"	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	6	12	18	24
Number of LLevels On Line	0	0	0	0	7	14	14	14
Number Systems Produced	0	0	0	6	6	6	6	6
Number of New Systems	0	0	0	0	6	6	6	6
Total Number of Systems	0	0	0	0	6	12	18	24
Total Number of AVs Fielded	0	0	0	0	60	120	180	240
UAV Attrition Information								
Contigency Theatre I ~ WestPac and IO								
Contigency ~ Yes(1) or No(0)	0	0.15	0.15	0.15	0.15	0.15	0.15	0.15
UAV Attrition Rate	0.0350	0.0873	0.0873	0.0873	0.0873	0.0873	0.0873	0.0873
Number of UAVs in Operating in Theatre	0	0	0	0	30	60	90	120
Attrition AVs	0	0	0	0	3	5	7	9
Contigency Theatre II ~ Atlantic & Mediterranean								
Contigency ~ Yes(1) or No(0)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
UAV Attrition Rate	0.0873	0.0873	0.0873	0.0873	0.0873	0.0873	0.0873	0.0873
Number of UAVs in Operating in Theatre	0	0	0	0	30	60	90	120
Attrition AVs	0	0	0	0	3	5	7	9
Pecrcent of AVs in "Available" for Service	0%	0%	0%	0%	95%	96%	96%	96%
Total Number of Attrition AVs	0	0	0	0	0	0	0	0
Total Number of Attrition Avs Produced	0	0	0	0	0	0	0	0
Total Number of AVs Produced	0	0	0	60	60	60	60	60
Production Line Open Costs	$ -	$ -	$ -	$ 10,000,000.00	$ 10,000,000.00	$ 10,000,000.00	$ 10,000,000.00	$ 10,000,000.00
Ground Equipment Information								
Number of Ground Control Equipment Produced	0	0	0	6	6	6	6	6
Number of Ground Control Equipment Fielded								
Number of Test Equipment Produced/Installed	0	0	0	7	7	0	0	0
Development Costs	$ 53,871,000.00	$ 50,189,000.00	$ 43,087,000.00	$ 29,427,000.00	$ -	$ -	$ -	$ -
Production Costs:								
AV Systems	$ -	$ -	$ -	$ 564,000,000.00	$ 564,000,000.00	$ 564,000,000.00	$ 564,000,000.00	$ 564,000,000.00
Ground Control Equipment Units	$ -	$ -	$ -	$ 14,100,000.00	$ 14,100,000.00	$ 14,100,000.00	$ 14,100,000.00	$ 14,100,000.00
Test Equipment Units (including installation)	$ -	$ -	$ -	$ 70,000,000.00	$ 70,000,000.00	$ -	$ -	$ -
Total Production Costs	$ -	$ -	$ -	$ 658,100,000.00	$ 658,100,000.00	$ 588,100,000.00	$ 588,100,000.00	$ 588,100,000.00
Total RDTE & Production Costs (Current Year $)	$ 53,871,000.00	$ 50,189,000.00	$ 43,087,000.00	$ 687,527,000.00	$ 658,100,000.00	$ 588,100,000.00	$ 588,100,000.00	$ 588,100,000.00
Inflation (Then Year)	$ 54,948,420.00	$ 52,216,635.60	$ 45,724,269.10	$ 744,201,335.67	$ 726,595,576.59	$ 662,296,118.77	$ 675,542,041.14	$ 689,052,881.97
PV(FY2000)	$ 49,061,089.29	$ 41,626,782.21	$ 32,545,631.59	$ 472,953,402.79	$ 412,289,843.40	$ 335,539,825.20	$ 305,680,912.24	$ 278,296,902.22
Cumulative Present Day ~ No Inflation	$ 53,871,000.00	$ 104,060,000.00	$ 147,147,000.00	$ 834,674,000.00	$ 1,492,774,000.00	$ 2,080,874,000.00	$ 2,668,974,000.00	$ 3,257,074,000.00
Cumulative Present Day ~ Inflation	$ 54,948,420.00	$ 107,165,055.60	$ 152,889,324.70	$ 897,090,660.36	$ 1,623,686,236.95	$ 2,285,982,355.72	$ 2,961,524,396.86	$ 3,650,577,278.83
Cumulative PV (FY2000)	$ 49,061,089.29	$ 90,687,871.49	$ 123,233,503.08	$ 596,186,905.87	$ 1,008,476,749.27	$ 1,344,016,574.48	$ 1,649,697,486.71	$ 1,927,894,398.93
Total Development and Production Costs (FY2000)	$ 53,871,000	$ 50,189,000	$ 43,087,000	$ 677,527,000	$ 648,100,000	$ 578,100,000	$ 578,100,000	$ 578,100,000
Cumulative Total (FY2000)	$ 53,871,000	$ 104,060,000	$ 147,147,000	$ 824,674,000	$ 1,472,774,000	$ 2,050,874,000	$ 2,628,974,000	$ 3,207,074,000
Cumulative Inflated Total (Then Year)	$ 54,948,420	$ 108,264,024	$ 156,153,574	$ 892,653,659	$ 1,626,061,501	$ 2,309,617,225	$ 3,019,864,754	$ 3,757,598,338
Inflation (Then Year)	$ 54,948,420	$ 52,216,636	$ 45,724,269	$ 733,377,014	$ 715,554,769	$ 651,034,495	$ 664,055,184	$ 677,336,288
PV (FY2000)	$ 49,061,089	$ 41,626,782	$ 32,545,632	$ 466,074,351	$ 406,024,992	$ 329,834,336	$ 300,384,842	$ 273,564,766
Cumulative PV (FY2000)	$ 49,061,089	$ 90,687,871	$ 123,233,503	$ 589,307,854	$ 995,332,846	$ 1,325,167,182	$ 1,625,552,024	$ 1,899,116,790
NPV (FY2000)	$ 2,941,358,061							
NPV (FY2000)	$ 2,986,164,397							
Cost per Squadron	$49,802,739.95							

UCAV Parametric Model RDT&E Worksheet Example.

F. DESCRIPTION OF RESEARCH DEVELOPMENT TEST AND EVALUATION (RDTE) AND PRODUCTION WORKSHEET

The RDTE and Production worksheet is divided into five sections labeled: FY Inputs, UAV Attrition Information, Production Line Open Costs, Ground Equipment Information, Development Costs, Production Costs, Total Development and Production Costs.

The FY Inputs section is formatted by FY number and by corresponding program year number. This section allows for the input of the number of squadrons standing up, the number of squadrons decommissioning, total number of squadrons, number of systems produced, number of new systems, total number of new systems, total number of Air Vehicles fielded. Each of these sections is input according to the FY and corresponding year in which the event took place.

The purpose of the UAV/Attrition Information section is to show how many additional UAV's need to be produced in the case of a contingency. This section deals with the Pacific and Mediterranean theatres and the UAV attrition rate, the number of UAV's operating in the theatre and the total number of attrition Air Vehicles. This portion of the model was not used for the purposes of this study but can be used with a Crystal Ball analysis if needed. Therefore the number of attrition Air Vehicles and total number of attrition AV's produced was zeroed out.

Production line open costs were assumed to be $25M over 10 years for the F/A-18C model and the $10M over 10 years for the UCAV model. The Ground Equipment information was not applicable to the F/A-18C model, but was in the UCAV model. In the UCAV model the number of Ground Equipment produced was determined by an Excel "IF-THEN" equation that stated: If the number of squadrons equals one, then the number of Ground Equipment produced was equal to zero. If not, the number of squadrons standing up for that year was multiplied by the total number of systems per squadron as input in the User Inputs worksheet.

Development Costs were imported directly from the User Inputs worksheet. Production Costs included the cost of the total number of AV's produced, total cost of the Ground Control Equipment (UCAV model only) and the cost of test equipment installation. For the purposes of this analysis it was assumed that the test equipment was already in place and did not have to be developed.

The RDTE and Production costs were then totaled in the next section of the model and then their inflation, PV, Cumulative present day value with and without inflation, and Cumulative PV in FY2000 dollars were calculated over the entire 20 year life cycle of the program. A copy of this section was made underneath and from that a total NPV of the RDTE and Production costs was completed and sent as an input to the Totals worksheet.

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FA-18C Life Cycle Cost (LCC) Analysis: Maintenance

Per I-level

WUC Description	MTBF	Failures/System	λ	Protection Level	1/system μ/hour	Required Spares(Norm) Norm	Poisson	Unit Cost	Annual Maint Costs 0.6	Initial Purchase Cost
Maintenance Inspections (03)	87343	1	0.00001	NonCritical	46.8	1.00	2	2	$ 8,500	$ 5,100	$ 17,000
Corrosion Prevention (04)	262030	1	0.00000	NonCritical	46.8	1.00	2	2	$ 1,144	$ 686	$ 2,288
General Functions (05)	30627	1	0.00003	NonCritical	46.8	1.00	2	2	$ 1,310	$ 786	$ 2,620
Non Aeronautical Work (09)	8734	1	0.00011	NonCritical	46.8	1.00	2	2	$ 107,168	$ 64,301	$ 214,336
Airframe and Flight Ctrl Sys (1")	6.69	53	0.14948	Critical	46.8	16.00	21	20	$ 4,798,612	$ 46,066,675	$ 95,972,240
Engine/APU (2")	49	8	0.02044	Critical	46.8	3.00	5	5	$ 3,305,031	$ 5,949,056	$ 16,525,155
Utility Systems (4")	26	14	0.03786	Critical	46.8	4.00	7	6	$ 2,403,142	$ 5,767,541	$ 14,418,852
Instrumentation (5")	41	9	0.02413	Critical	46.8	3.00	5	4	$ 1,482,930	$ 2,669,274	$ 5,931,720
Comm Nav IFF (6")	53.45	7	0.01871	Critical	46.8	2.00	4	3	$ 3,618,474	$ 4,342,169	$ 10,855,422
Radio Radar Nav/Weps CS (7")	6.09	58	0.16420	Critical	46.8	17.00	22	21	$ 1,595,278	$ 16,271,836	$ 33,500,838
Airborne Expendable Ordnance (8)	65507	1	0.00002	Critical	46.8	1.00	3	2	$ 1,592	$ 955	$ 3,184
Emergency Equip (91)	1050.22	1	0.00095	Critical	46.8	1.00	2	2	$ 7,980	$ 4,788	$ 15,960
Personnel Equip (96)	2902.46	1	0.00036	NonCritical	46.8	1.00	2	2	$ 5,900	$ 3,540	$ 11,800
Explosive Devices (97)	588.17	1	0.00170	Critical	46.8	1.00	3	2	$ 3,290	$ 1,974	$ 6,580
									$ 81,148,601	$ 177,477,995

Cost per Squadron: $ 81,148,681
Cost per I-level: $ 177,477,995
Cost per System: $ 37,869,384

Maintenance Shipments/System (Transportation cost): 157

FY Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Squadrons "Standing Up"	0	0	0	0	2	6	2	4	4	6	1	1	1	1
Squadrons "Decomming"	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of Squadrons	0	0	0	0	3	9	12	16	20	26	27	28	29	30
Number of New I-Levels	0	0	0	0	7	7	0	0	0	0	0	0	0	0
Number of I-Levels On Line	0	0	0	0	7	14	14	14	14	14	14	14	14	14
Number of New Systems	0	0	0	0	3	6	3	4	4	6	1	1	1	1
Total Number of Systems	0	0	0	0	3	9	12	16	20	26	27	28	29	30

NPV: $ 11,735,568,980

F/A-18C Parametric Model O&M Worksheet Example.

UCAV Life Cycle Cost (LCC) Analysis: Maintenance

Per I-level

WUC Description	MTBF	Failures/System	λ	Protection Level	1/system μ/hour	Required Spares(Norm) Norm	Poisson	Unit Cost	Annual Maint Costs 0.6	Initial Purchase Cost
Maintenance Inspections (03)	104811.6	1	0.00001	NonCritical	8.4	1.00	2	2	$ 8,500	$ 5,100	$ 17,000
Corrosion Prevention (04)	314436	1	0.00000	NonCritical	8.4	1.00	2	2	$ 1,144	$ 686	$ 2,288
General Functions (05)	36992.4	1	0.00003	NonCritical	8.4	1.00	2	2	$ 1,310	$ 786	$ 2,620
Non Aeronautical Work (09)	10480.8	1	0.00010	NonCritical	8.4	1.00	2	2	$ 107,168	$ 64,301	$ 214,336
Airframe and Flight Ctrl Sys (1")	8.028	15	0.12456	Critical	8.4	5.00	8	7	$ 4,798,612	$ 14,395,836	$ 33,590,284
Engine/APU (2")	59	3	0.01703	Critical	8.4	1.00	3	2	$ 3,305,031	$ 1,983,019	$ 6,610,062
Utility Systems (4")	32	4	0.03155	Critical	8.4	2.00	4	3	$ 2,403,142	$ 2,883,770	$ 7,209,426
Instrumentation (5")	50	3	0.02011	Critical	0.4	1.00	2	2	$ 1,402,930	$ 869,758	$ 2,965,800
Comm-Nav-IFF (6")	64.14	2	0.01559	Critical	8.4	1.00	3	2	$ 3,618,474	$ 2,171,084	$ 7,236,948
Radio-Radar Nav/Weps CS (7")	7.308	17	0.13684	Critical	8.4	5.00	8	7	$ 1,595,278	$ 4,785,834	$ 11,166,946
Airborne Expendable Ordnance (8)	78608.4	1	0.00001	Critical	8.4	1.00	3	2	$ 1,592	$ 955	$ 3,184
Ground Control Equipment	323.4	1	0.00309	Critical	8.4	1.00	3	2	$ 4,000,000	$ 2,400,000	$ 8,000,000
Ground Data Terminal	355.08	1	0.00282	Critical	8.4	1.00	3	2	$ 1,200,000	$ 720,000	$ 2,400,000
Explosive Devices (97)	705.804	1	0.00142	Critical	8.4	1.00	3	2	$ 3,290	$ 1,974	$ 6,580
									$ 30,303,104	$ 79,425,534

Cost per Squadron: $ 30,303,104
Cost per I-level: $ 79,425,534
Cost per System: $ 7,070,724

Maintenance Shipments/System (Transportation cost): 52

NPV: $ 6,803,493,918

UCAV Parametric Model O&M Worksheet Example.

G.   DESCRIPTION OF MAINTENANCE WORKSHEET

This worksheet was divided into two sections, the Per I-Level and the FY Summary blocks. In column B of the I-level section the Work Unit Code Descriptions were given for all of the two-digit work unit codes of the Air Vehicle. Column C took

the MTBF inputs from the User Inputs Component Inputs Section and applied them to this section.

Column D was the failures per system, which was calculated by taking the AV Flight hours per year divided by the MTBF of the particular component (rounded to the nearest whole number). Column E is λ which was calculated by using the data in Column C into the formula:

$$\lambda = 1/\textbf{MTBF}$$

The protection level in column F was from the User Inputs Page where the Protection level of each component is stated and relates to either a Critical or Non-Critical Component. Column G calculated the number of spares based on the formula:

$$\textbf{Total Spares = AV Hours*Spare Level Factor}$$

Where the AV Hours and the Spare Level Factor data came from the User Inputs section.

The average number of failures in column H was calculated by taking the number of Systems per I-level, the failure rate, or λ and the total operating time and placing them into the formula:

$$\textbf{Spares Required}: \ \mu = \textbf{k}\lambda\textbf{t}$$

where μ = average number of failures, k = number of systems, λ = 1/mean time between failure (MTBF) and t = total operating time. The equation was solved for μ and then went to the Poisson table and solve for the number of spares by looking up the desired protection level under the column that contains the column with the μ value.

The required spares were calculated in two methods, the first used a Normal distribution and the second used a Poisson distribution. The Normal distribution used a

NORMINV Excel function, which takes the probability, which was the Critical or Non-Critical percentage, multiplied by the mean or failures per hour and the standard deviation or square root of the failures per hour. For example:

Normal Distribution of Spares = NORMINV(.75 * 16.0 * √16.0)

This equation then gave the number of required spares for the individual WUC.

The Poisson distribution calculation of spares took the Critical or Non-Critical Protection level percentage and went to the Poisson Table Worksheet and looked vertically until it found the protection level percentage and the corresponding spare based on the percentage stated in the table.

The Unit Cost was taken from the User Inputs page. The Annual Maintenance Costs were calculated by taking the Failures per hour * the cost of each unit * percentage assumed that maintenance costs are of total unit cost. For example:

Annual Maintenance Costs = 16.00 * $8400 * 60%

The 60 percent factor is taken from Blanchard's book in chapter 2 where he describes the maintenance costs as being 60 percent of the unit cost. Initial Purchase cost of the components was derived by the calculation:

Initial Spares Purchase Cost = Poisson distribution of Spares * Unit Cost

The second section of this worksheet was the Summary Blocks. These blocks were labeled as seen in column B. The first section of blocks from rows 31-38 described the year of the program, inputs for the number of squadrons standing up, decommissioning, and total number of squadrons as well as the new I-levels and total number of I-levels on-line.   Additionally, the number of new systems and total number of systems was calculated from the input information.

I-level Activation Cost was not applicable as the 14 I-levels already existed. Annual I-Level Operating Cost was calculated over the Life Cycle of the program (20 years in the formula:

Total Operating Cost = Annual I-Level Operating Cost * Number of I-levels online

The Transportation Cost was calculated using an Excel "IF" statement that stated:

If the number of I-levels < number of squadrons, then: the number of shipments * total number of systems * transportation cost per shipment, if not then the number is equal to Zero

Petroleum, Oil and Lubricant (POL) costs were calculated using the formula in the worksheet:

=UAV's per System*Total number of systems*POL Cost*AV Flight Hours/year

The Initial Spare purchase total row was calculated by taking the number of new I-levels on line and multiplying that number by the Cost of spares per I-level. If there were no new I-levels, then no initial purchase spares were needed.

Maintenance Costs were totaled by taking the total number of I-levels online and multiplying it by the cost of maintenance per squadron total.

The next rows of Total, Inflation, Present Value (PV) and Net Present Value (NPV) were calculated from the previously described rows to provide a NPV as seen in the example below for the Operations and Maintenance Worksheet that was transferred to the Total worksheet.

Total (FY2000)	$ -	$ -	$ -	$ -	$ 1,005,164,481
Inflation (Then Year)	$ -	$ -	$ -	$ -	$ 1,109,782,807
PV (FY2000)	$ -	$ -	$ -	$ -	$ 629,720,569
NPV	$ 6,471,646,106				

Example of the Total, Inflation, PV and NPV Spreadsheet Rows.

FA-18C Life Cycle Cost (LCC) Analysis: Overall

	Total	FY00	FY01	FY02
Year		1	2	3
Manning	$ 10,807,828,000	$ -	$ -	$ -
Training	$ 623,812,189	$ -	$ -	$ -
RDTE & Producton	$ 10,775,200,000	$ 30,000,000	$ 11,800,000	$ 10,100,000
Operations & Maintenance	$ 39,034,412,090	$ -	$ -	$ -
Total (Then Year)	$ 61,241,252,279	$ 30,000,000	$ 11,800,000	$ 10,100,000
Inflation adjusted (Then Year)	$ 79,972,216,591	$ 30,600,000	$ 12,276,720	$ 10,718,201
PV (FY 2000)	$ 20,778,717,833	$ 27,321,429	$ 9,786,926	$ 7,629,004
Cumulative PV (FY2000)		$ 27,321,429	$ 37,108,355	$ 44,737,358

Total Inflated	$ 79,972,216,591
Total PV	$ 20,778,717,833

Design to Unit Cost		$ 15,460,745
Systems Built	30	
Production Cost	$ 5,565,868,311.86	

LCC to O&M Cost (LCC cost/squadron and u	$ 692,623,928	$ 57,718,661
Systems Built	30	
Total LCC	$20,778,717,833	

Cj values

O&M Cost to Sqaudron (O&M cost/squadron	$1,301,147,069.65
Systems Built	30

F/A-18C Parametric Model Total Worksheet Example.

UCAV Life Cycle Cost (LCC) Analysis: Overall

	Total	FY00	FY01	FY02
Year		1	2	3
Manning	$ 12,406,644,000	$ -	$ -	$ -
Training	$ 704,906,782	$ -	$ -	$ -
RDTE & Producton	$ 6,097,574,000	$ 53,871,000	$ 50,189,000	$ 43,087,000
Operations & Maintenance	$ 21,431,082,597	$ -	$ -	$ -
Total (Then Year)	$ 40,640,207,379	$ 53,871,000	$ 50,189,000	$ 43,087,000
Inflation adjusted (Then Year)	$ 40,640,207,379	$ 53,871,000	$ 50,189,000	$ 43,087,000
PV (FY 2000)	$ 12,733,649,312	$ 48,973,636	$ 41,478,512	$ 32,371,901
Cumulative PV (FY2000)		$ 48,973,636	$ 90,452,149	$ 122,824,050

Total Inflated	$ 40,640,207,379
Total PV	$ 12,733,649,312

Design to Unit Cost		$ 48,383,327
Systems Built	60	
Production Cost	$ 2,902,999,605.78	

Design to O&M Cost		$ 212,227,489
Systems Built	60	
Total LCC	$12,733,649,312	

UCAV Parametric Model Total Worksheet Example.

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H.   LIFE CYCLE COST OVERALL WORKSHEET DESCRIPTION

The Overall worksheet is a summary of the Manning, Training, RDTE/Production and O&M worksheets in the parametric model. This worksheet provides an executive snapshot of each worksheet category's total LCC.

The format of the worksheet the same format as the individual cost category worksheets. The columns were labeled as *Total*, then by *FY*, and then by the *Program Year* below the applicable FY category as seen in the example:

	Total	FY00
Year		**1**
Manning	$ 12,406,644,000	$ -
Training	$ 704,906,782	$ -

Example of Overall Column Layout.

Each worksheet category row input was taken directly from the labeled worksheet as seen the example:

Manning	$ 12,406,644,000	$ -	$ -
Training	$ 704,906,782	$ -	$ -
RDTE & Producton	$ 6,097,574,000	$ 53,871,000	$ 50,189,000
Operations & Maintenance	$ 21,431,082,597	$ -	$ -

Example of Worksheet Category Rows.

Once the information was compiled from the separate worksheets, the *Then Year* total for all the FY columns was derived. The Inflation Rate was calculated for each column with the Excel formula:

=Then Year Column Total*(1+InflateRate from User Inputs worksheet) [Program Year]

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Once the inflation adjustment columns were calculated the Present Value (PV) for each FY column was calculated with the Excel formula:

=Inflation Adjusted total/(1+Discount Rate + Inflation Rate) $^{\text{Program Year}}$

Once the PV columns were calculated, the Inflation Adjusted Row was added to the PV row and from that the Cumulative PV for FY2000 was determined.

The Total Inflated Costs and the Total PV costs were calculated by totaling the Inflation Adjusted row and the PV (FY2000) row respectively.

The final section of the Overall costs page is the comparison of the Design to Unit Cost and the Design to O&M cost. These costs were calculated to demonstrate the NPV of the cost of RDTE and Production per Air Vehicle and the cost of Operations and Maintenance per Air Vehicle over the entire 20-year life cycle. An example of the worksheet blocks is shown in the example below.

Design to Unit Cost		$ 15,135,701
Systems Built	30	
Production Cost	$ 5,448,852,473.31	

Design to O&M Cost		$ 57,393,617
Systems Built	30	

Example of the Design to Unit and Design to O&M cost blocks.

The equations used to calculate these costs were simply:

(RDTE & Production Cost ÷ Systems Built) ÷ # of Aircraft per squadron

and

(LCC ÷ Systems Built) ÷ # of Aircraft per squadron

The final block of the Overall worksheet calculated the Total Life Cycle Cost of the Air Vehicle from the data that was sent from the individual cost area worksheets. This block was then transferred back to the User Inputs worksheet so that the user was able to see the LCC impact that a change in the data inputs had made.

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APPENDIX E. SHIP COST MODEL

A.   INTRODUCTION

This aspect of the analysis establishes the acquisition cost and 20-year life cycle cost for the SEA QUIVER logistics support ship.

B.   SCOPE AND LIMITATIONS

A pre-formulated spreadsheet model was used to determine the LCC of a SEA QUIVER performing peacetime operations. The outputs from the model were intended for high-level cost estimation, and not to derive precise identification of system costs. These formulations are not intended for specific program cost justification, but to provide a rough order of magnitude during the concept development of a weapons system.

The life cycle model does not account for costs associated with production runs throughout the existence of the program. Additionally, RDT&E costs are included in the yearly operations costs rather than the acquisition cost.

C.   METHODOLOGY AND ASSUMPTIONS

Baselines cost figures, of an AOE Supply class ship, were acquired from VAMOSC [VAMOSC, 2001] to use in the formulation of acquisition and total LCC for one SEA QUIVER. The cost figures for the SEA QUIVER were also scaled to 50 percent of the AOE class ship to reflect the smaller size of the conceptual logistic ship.

Analogy estimation was employed to generate the SEA QUIVER cost data, taking the AOE system data and adjusting it to assimilate the intended parameters of the SEA QUIVER system.

The computed net present value was multiplied by 10, the number of projected SEA QUIVERS in the fleet, to derive a total cost to support the aggregate CROSSBOW squadrons.

Two theses were used in the formulation of the acquisition and annual O&M cost estimations. The first thesis written by Kirk J. Loftus [Loftus, 2000] dealt with the estimation of the acquisition costs for conventional surface ships. James M. Brandt

[Brandt, 2000] wrote the second thesis that was used in the formulation of annual O&M costs, for U.S. Navy (Non-Nuclear) ships.

The Loftus thesis, dealing with estimation of acquisition costs, formulas were derived that calculated ship cost with respect to the variables of Ship Length (feet), Displacement (Light Tons or LT), Shaft Horsepower (SHP), and the number of engines. The thesis by James M. Brandt dealt with the estimation of O&M costs for a ship based on three inputs for analysis. The O&M costs were estimated by using the Displacement (LT), manning or length of the ship (feet). The AOE data was input into these two different models for acquisition and O&M costs in order to establish the baseline for comparison.

Once established, the AOE baseline data was then scaled to reflect the notional characteristics of the SEA QUIVER. To imitate similar characteristics of a SEA ARCHER, the length and SHP scaling was based on the notional SEA ARCHER configuration. However, due fuel and stores requirements and maintenance space requirements, the volume of the SEA QUIVER had to be scaled larger than that of the SEA ARCHER. Therefore, the resultant displacement was scaled to be 50 percent of an AOE-1 class ship and became 24,400 LT. The scaled data for the SEA QUIVER was input into the costing equations to produce a resultant cost derivation. Figure 1 demonstrates the specific set up for the acquisition spreadsheet and figures 2 and 3 represent the O&M formulations and the subsequent LCC calculations.

O&M ship costs, generated from the spreadsheet, were compared to actual VAMOSC CAIG data for O&M costs of the AOE *Supply* class [VAMOSC, 2000]. The SEA QUIVER and the AOE were then compared in the three different categories, demonstrated in Figures 2 and 3, of displacement, manning and length O&M cost.

Total LCC was obtained by the combination of the calculated O&M costs, Military Cost Handbook RDT&E data and VAMOSC training and manning cost information. O&M costs were calculated from the average of the O&M cost estimations provide from the categories of Displacement, Manning and Ship length. This average cost input became the input factor for the 20 year LCC estimation.

RDT&E costs were derived from cost data listed in the Military Cost Handbook, which was used as input into the spreadsheet model for overall LCC calculation. Because the SEA ARCHER and SEA QUIVER share similar technologies, SEA QUIVER RDT&E was set at 25 percent of the SEA ARCHER RDT&E costs to account for shared technology development, economies of scale, and elimination of continuous launch and recovery operations.

Training and Manning costs were estimated by using VAMOSC data to produce an average of VAMOSC FY 98-00 AOE-1 class manning and training costs. These costs were calculated in then year dollars and inflated to then year costs at an inflation rate of 2 percent. The present value (PV) was calculated by using the formula:

$$\text{Total FY \$}/(1+(\text{Inflation Rate\%} + \text{Discount rate\%}))^{\text{Year number}}$$

Following the PV calculation, the data was totaled to show the Net Present Value (NPV) LCC for one ship. Cost areas are demonstrated at the end of this appendix.

The average of this data was found to be $177K for training and $19M for manning. Each was assumed to be static over the 20 years of the program. The new ship force would be reduced from 667 personnel (AOE manning) to 110 personnel on the SEA QUIVER. Therefore, the manning and training percentages for the SEA QUIVER were then assumed to be 19 percent (110/667) of the AOE. Although the manpower numbers did not change from the notional SEA ARCHER manning, the type rating areas for personnel was assumed to have changed in order to reflect a repair/replenishment mission vice a power projection platform.

D. ANALYSIS

It was determined that the SEA QUIVER had a LCC of 11 percent more than that of the AOE-1. This overall increase was due to the 98 percent increase in RDT&E costs as a result of the implementation of new technologies in the ship design and systems. The cost can also be attributed to the increased repair capability of the SEA QUIVER

(IMA) with the commensurate repair equipment cost. There was, however an 86 percent reduction in manpower costs and a 46 percent reduction in O&M costs.

Despite the reduction in manning requirements, training costs were found to remain at the same level of costs. This cost was reflective of the increased training in advanced maintenance and replenishment systems.

Once the baseline cost scenario was established, the manpower data was modified to reflect a change in the maintenance concept for component repair on board SEA QUIVER. It was assumed that DLRs would be routed from the Organizational (e.g. squadron) level to Original Equipment Manufacturer (OEM) instead of being repaired at an I-level, on board SEA QUIVER. Manpower was assumed to remain static at 110 people for the SEA QUIVER. However, the ratings of the personnel intended for the I-level component would be changed to reflect personnel ratings for other support functions such as fuel/stores and medical assistance.

E.   CONCLUSIONS

<u>Life Cycle Costs of the SEA QUIVER totaled $839M for one ship and $8.4B for 10 ships (two SEA QUIVER per CROSSBOW squadron)</u>. Compared to the AOE-1 class, LCC increased by $160M because of the 98 percent increase in RDT&E costs over the life cycle. This increase was due to the advanced technological concepts introduced into the SEA QUIVER. Despite the increase in LCC, SEA QUIVER reduced logistics delay time and refueling time with increased repair capability and pump speed capability resulting from the additional RDT&E outlays

The reduction in O&M costs was significant with the reduction in ship displacement when compared to the AOE-1 class. The size difference of the SEA QUIVER drove a decrease in the O&M costs. This savings in the O&M cost category shifted to the RDT&E category in order to fund the technological advances.

With the elimination of the I-level, manpower resources could be maintained, or reduced, to reflect the purely support provisioning and replenishment functions.

The argument could be made that if the cost of the SEA QUIVER is 11 percent more than the cost of the AOE *Supply* class, then why not keep producing what we have?

The SEA QUIVER would provide stealth of the smaller ships profile, enhanced repair capability of the IMA, increased refueling pump speed, reduced manning requirements, and ultimately, a vessel sustainable beyond normal ship life spans with PHM and CBM enabling a longer effective life span.

Acquisition Cost Model

Ship Type	Length	Disp	SHP(khp)	Number Eng	MV2	RSE	Beam	# Ships	Cost Basis	Total Cost ($)
Sea Quiver	513	10000	82	8			100	2		
Formula($M)	$505.14	$508.93	$886.34	$693.04	$751.43					
($)	$505,140,200.00	$508,930,000.00	$886,344,600.00	$693,040,000.00	$751,429,660.00				MV2	$1,502,859,320.00
Average	$648,363,700.00									
DDG-51	509	8300	100	4			59	49		
Formula($M)	$500.32	$448.92	$1,058.16	$346.52	$741.32					
($)	$500,318,600.00	$448,920,000.00	$1,058,160,000.00	$346,520,000.00	$741,317,681.36				MV2	$36,324,566,386.44
Average	$588,479,650.00									
CG	567	9600	80	4			55	27		
Formula($M)	$570.23	$494.81	$867.25	$346.52	$946.96					
($)	$570,231,800.00	$494,810,000.00	$867,254,000.00	$346,520,000.00	$946,957,418.18				MV2	$25,567,850,290.91
Average	$569,703,950.00									
CV	1062.5	80800	280	8			130	2		
Formula($M)	$1,167.51	$3,008.17	$2,776.31	$693.04	$2,540.35					
($)	$1,167,507,500.00	$3,008,170,000.00	$2,776,314,000.00	$693,040,000.00	$2,540,353,100.00				MV2	$5,080,706,200.00
Average	$1,911,257,875.00									
AOE	754	48800	100	4			107	4		
Formula($M)	$795.64	$1,878.57	$1,058.16	$346.52	$1,411.73					
($)	$795,641,600.00	$1,878,570,000.00	$1,058,160,000.00	$346,520,000.00	$1,411,732,314.02				No Eng	$1,386,080,000.00
		38495.28689								
Average	$1,019,722,900.00									

Ship Type		Disp (LT)	Manning	LOA (ft)	Year	
					1	2
AOE		48800	667	754		
Annual O&S Cost (FY$98)		$87,891,407.29	$37,434,043.23	$49,115,730.81		
Standard Error E (L)		$60,047,409.46	$28,318,853.71	$35,594,170.12		
Standard Error (U)		$115,735,405.11	$49,480,318.35	$67,774,796.94		
1.0 Direct Unit Cost		$54,853,027.29	$23,362,586.38	$30,653,127.60		
	+ or -	$13,921,698.33	$5,929,424.42	$7,779,763.78		
2.0 Direct Intermediate Maintenance Cost		$887,703.21	$378,083.84	$496,068.88		
	+ or -	$9,587.19	$4,083.31	$5,357.54		
3.0 Direct Depot Maint Cost		$29,461,199.72	$12,547,891.29	$16,463,592.97		
	+ or -	$318,180.96	$135,517.23	$177,806.80		
4.0 Indirect O&S Cost		$2,680,687.92	$1,141,738.32	$1,498,029.79		
	+ or -	$28,951.43	$12,330.77	$16,178.72		
TOTAL		$87,882,618.15	$37,430,299.83	$49,110,819.23		
Average		$58,141,245.74				
Compared to VAMOSC 1996 average of:		$20,000,000.00				
Inflation Rate	0.02					
Years of pgm	20					
Discounted cost		$59,142,482.69	$25,189,518.77	$33,050,173.49		
Cum Discounted Cost (20 years)		$147,025,100.84	$62,619,818.60	$82,160,992.72		
Dicount Rate	0.1					

	1	2
RDTE		
Training	$177,804.33	$177,804.33
O&M	$58,141,245.74	$58,141,245.74
Manning	$19,085,432.33	$19,085,432.33
Total Then Year	$77,404,482.40	$77,404,482.40
Inflated Then Year	$78,952,572.05	$80,531,623.49
PV	$70,493,367.90	$64,199,317.20
NPV	**$679,345,540.33**	
4 ships	**$2,717,382,161.33**	
10 Ships	**$6,793,455,403.34**	
	0.117729114	

Ship Type		Disp (LT)	Manning	LOA (ft)	Year 1	2
Sea Quiver		10000	110	513		
Annual O&S Cost (FY$98)		$32,999,166.33	$9,687,615.11	$26,522,486.76		
Standard Error E (L)		$22,545,030.44	$7,328,680.83	$19,220,846.15		
Standard Error (U)		$43,453,302.23	$12,805,089.66	$36,598,379.47		
1.0 Direct Unit Cost		$20,594,779.71	$6,046,040.59	$16,552,683.98		
	+ or -	$5,226,955.09	$1,534,485.10	$4,201,071.20		
2.0 Direct Intermediate Maintenance Cost		$333,291.58	$97,844.91	$267,877.12		
	+ or -	$3,599.55	$1,056.73	$2,893.07		
3.0 Direct Depot Maint Cost		$11,061,320.55	$3,247,288.59	$8,890,337.56		
	+ or -	$119,462.26	$35,070.72	$96,015.65		
4.0 Indirect O&S Cost		$1,006,474.57	$295,472.26	$808,935.85		
	+ or -	$10,869.93	$3,191.10	$8,736.51		
TOTAL		$32,995,866.42	$9,686,646.35	$26,519,834.51		
Average		$23,067,449.09				
Compared to VAMOSC 1996 average of:		$20,000,000.00				
Inflation Rate	0.02					
Years of pgm	20					
Discounted cost		$22,205,272.21	$6,518,835.31	$17,847,088.38		
Cum Discounted Cost (20 years)		$55,201,138.62	$16,205,481.66	$44,366,922.89		
Dicount Rate	0.1					

	Year 1	Year 2
RDTE	$68,475,000.00	$78,975,000.00
Training	$177,804.33	$177,804.33
O&M	$23,067,449.09	$23,067,449.09
Manning	$3,053,669.17	$3,053,669.17
Total Then Year	$94,773,922.60	$105,273,922.60
Inflated Then Year	$96,669,401.05	$109,526,989.07
PV	$86,311,965.22	$87,314,245.11

NPV	**$769,996,552.56**
10 ships	**$7,699,965,525.58**
Reduc in O&S	60.3%
Increase in RDTE	98.4%
Increase in LCC	11.8%
Increase in LCC ($)	$90,651,012.22

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APPENDIX F. MODULE PROCESS TIMES AND DISTRIBUTIONS

Function/Sub-Function	Module	Process Time	Delay/Route Time

a. Initialize Squadron

(Flight) Station
Chance   .653, .347
Delay   23
Route   0

b. Assign type failure

Chance   .38, .34, .115, .06, .05,
.04, .01
else
.005

c. O-Level Repair

   i. Store aircraft until matching part is ready
               Route   Process_Delay_Time
                                               +(Supply_time_scaler*
                                               Process_Delay_Time)

   ii. Replace Part at Squadron
(Squadron)   Adv Server   Process_time +   Process_Delay_Time
                         (Maint_time_scaler   +(Supply_time_scaler*
                         *Process_time)   Process_Delay_Time)

   iii. Return aircraft to service after 23hr delay
               Route   23

d. Route items for repair
               Chance   .5, .475, .025

   i. Route to Squadron Shop
               Route   Process_Delay_Time
                                               +(Supply_time_scaler*
                                             Process_Delay_Time)

   ii. Route to IMA by part type
               Route x 8   0

Function/Sub-Function	Module	Process Time	Delay/Route Time
iii. Route offship for major repair			
	Route		24+ (Supply_time_scaler *24)

e. IMA Repair

(IMA_Airframes)	Adv Server	AIMD_Process_time+ (AIMD_Process_time* Maint_time_scaler)	Process_Delay_Time +(Supply_time_scaler* Process_Delay_Time)
(IMA_CommNavIFF)	Adv Server	same as above	same as above
(IMA_RNAVWCS)	Adv Server	same as above	same as above
(IMA_Ordnance)	Adv Server	same as above	same as above
(IMA_Utility Sys)	Adv Server	same as above	same as above
(IMA_Power Plants)	Adv Server	same as above	same as above
(IMA_Instruments)	Adv Server	same as above	same as above
(IMA_GroundEqpt)	Adv Server	same as above	same as above

f. Ship DLR

	Route		2880 + (Supply_time_scaler * 2880)+ (Maint_Time_scaler *2880)

VARIABLES

Total Flight Hours	CNAV_Spares	GCE_GTE_Spares
FMC_AC	Engine_Spares	TOTAL_AC
INSTR_Spares	CAD_Spares	Supply_time_scaler
AF_Spares	UTIL_Spares	Maint_time_scaler
RNAV_Spares		

APPENDIX G. SIMULATION RUNS

System Reliability Adjustment Data

	.00	.05	.10	.15	.20	.25	.30	.40	.50
Down Time									
	9.09	3.44	1.07	6.25	6.20	6.66	0.49	8.63	7.38
	0.19	7.20	6.43	0.24	0.01	4.51	5.53	8.72	9.26
	6.44	5.50	7.15	6.77	0.00	0.34	9.93	6.65	7.60
	0.87	7.02	2.36	9.86	5.69	6.69	5.00	4.05	1.93
	4.68	2.45	4.97	0.22	9.42	9.16	7.48	7.13	1.31
	8.97	7.44	6.48	1.81	1.16	0.80	.84	.68	0.70
	4.45	1.10	9.99	0.80	1.46	1.26	0.18	2.03	2.75
	9.03	2.32	6.64	9.64	0.84	1.12	5.64	2.58	0.37
	2.81	2.04	7.39	9.77	5.49	8.30	7.59	4.46	2.70
	4.15	4.90	0.23	1.98	3.39	4.60	5.10	0.90	3.75
Down Time (Sum)	**30.68**	**23.41**	**42.71**	**17.34**	**93.66**	**13.44**	**95.78**	**62.83**	**57.75**
Down Time (Avg)	*3.07*	*2.34*	*4.27*	*1.73*	*9.37*	*1.34*	*9.58*	*6.28*	*5.78*
Total Flight Hours									
	67.39	22.51	23.97	013.50	005.60	92.60	020.90	021.90	032.50
	82.78	95.74	038.00	030.70	045.60	070.20	082.60	131.50	097.40
	17.16	82.90	34.74	031.00	010.20	77.10	60.42	018.50	057.70
	83.42	50.65	68.46	77.73	80.66	54.12	95.53	097.50	080.30
	036.60	041.80	018.70	132.80	148.10	130.00	145.20	149.60	103.60
	56.93	010.40	74.80	020.80	043.80	077.60	078.60	067.30	139.80
	015.10	051.90	39.70	044.20	073.10	068.50	123.60	100.60	169.20
	064.10	75.00	76.65	84.70	060.30	035.30	057.50	092.90	107.30
	012.70	39.28	38.54	007.60	006.80	000.60	008.70	046.80	086.70
	012.90	92.95	56.37	33.15	72.17	60.67	036.90	067.50	094.20
Total Flight Hours (Sum)	**749.08**	**863.13**	**569.93**	**0176.18**	**0346.33**	**0166.69**	**0509.95**	**0794.10**	**0968.70**
Total Flight Hours (Avg/100)	*.75*	*.86*	*.57*	*0.18*	*0.35*	*0.17*	*0.51*	*0.79*	*0.97*
Total Failures									
	35.26	18.77	03.13	77.39	78.33	75.36	72.28	78.31	65.26
	56.68	03.50	17.52	02.88	86.36	86.16	74.92	77.31	59.62
	80.60	28.13	21.26	03.34	26.94	14.92	99.48	87.27	80.70
	43.89	52.33	91.16	12.20	08.60	89.81	00.92	71.15	63.96
	11.34	30.63	17.55	03.83	04.56	00.31	87.17	74.49	92.65
	41.68	33.48	17.98	23.43	06.65	86.79	84.31	82.13	48.73
	88.58	39.86	06.79	22.96	13.74	05.41	99.82	19.93	89.56
	40.07	47.59	28.18	28.49	17.16	60.93	85.01	95.38	77.27

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29.70	28.81	36.65	06.62	08.40	98.72	92.09	90.02	65.52
46.18	24.63	04.98	25.51	09.64	88.65	91.36	86.24	66.22
Total Failures (Sum)								
273.98	**307.73**	**945.20**	**106.65**	**060.38**	**907.06**	**887.36**	**862.23**	**709.49**
Total Failures (Avg/100)								
.27	*.31*	*.95*	*.11*	*.06*	*.91*	*.89*	*.86*	*.71*
Op Avail								
3.44	3.00	9.87	6.93	6.77	6.66	6.52	0.32	9.89
5.86	6.72	0.93	0.63	4.29	2.55	3.78	6.39	8.55
8.74	3.01	1.65	8.84	8.63	1.94	5.49	8.01	1.65
6.01	4.76	9.56	8.57	8.31	8.85	0.15	7.75	7.56
8.83	0.35	2.00	6.86	8.58	8.66	0.80	1.42	0.76
3.28	4.38	3.45	8.10	7.39	0.61	3.25	3.77	8.77
6.88	9.75	6.50	9.52	2.89	9.43	5.09	6.28	9.35
8.19	2.96	2.58	4.41	9.43	7.52	1.00	4.23	3.90
5.70	2.22	3.07	9.50	9.71	5.73	7.56	2.90	4.00
8.82	5.39	7.85	9.15	6.38	3.77	0.98	3.01	4.11
Op Avail (Sum)								
45.75	**52.54**	**47.46**	**82.51**	**02.38**	**95.72**	**14.62**	**44.08**	**58.54**
Op Avail (Avg/10)								
.46	*.53*	*.47*	*.83*	*.02*	*.96*	*.15*	*.44*	*.59*

MAINTENANCE TIME ADJUSTMENT DATA

	.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Down Time	9.09	9.61	8.06	4.71	4.73	3.70	0.49	4.40	.62	.77	.21
	0.19	9.73	7.92	6.20	5.28	4.57	4.41	1.86	.29	.02	.73
	6.44	2.90	4.44	0.00	7.20	7.45	0.77	.46	1.37	.62	.72
	0.87	3.01	5.26	4.49	3.37	0.31	0.71	3.18	.95	.78	.01
	4.68	2.17	3.07	9.22	3.62	7.28	.48	2.52	.73	.05	.58
	8.97	3.90	2.82	0.20	0.45	.43	.04	.55	.09	.92	.47
	4.45	8.49	3.11	4.06	9.78	6.76	9.45	6.69	4.36	.96	.01
	9.03	9.68	2.43	9.03	3.56	3.77	2.07	.34	.86	.56	.20
	2.81	5.46	8.03	2.73	7.08	0.74	.41	.28	.10	.40	.65
	4.15	3.92	8.68	1.34	8.37	1.74	.81	.58	.71	.69	.55
Down Time (Sum)	**30.68**	**18.86**	**93.82**	**71.99**	**63.44**	**35.74**	**10.63**	**01.87**	**0.08**	**1.79**	**5.13**
Down Time (Avg)	*3.07*	*1.89*	*9.38*	*7.20*	*6.34*	*3.57*	*1.06*	*0.19*	*.01*	*.18*	*.51*
Total Flight Hours	67.39	96.54	024.30	059.10	061.10	084.10	108.00	063.20	159.40	165.00	157.80
	82.78	99.10	019.60	011.10	054.10	046.00	059.30	089.70	129.70	139.60	140.60
	17.16	010.00	60.05	031.40	039.10	040.40	115.60	143.90	105.60	143.20	174.10
	83.42	90.36	047.70	076.20	073.30	090.60	082.50	083.60	143.00	161.80	153.00
	036.60	028.40	020.90	031.40	076.90	076.90	136.80	129.40	101.20	174.70	175.60
	56.93	093.00	108.90	134.70	144.00	150.50	157.40	178.10	216.90	213.60	219.20
	015.10	24.58	66.13	59.38	23.18	57.33	03.07	53.92	89.00	070.40	108.80
	064.10	89.76	71.81	002.00	068.40	075.40	102.80	169.90	145.80	156.20	178.20
	012.70	72.67	033.70	095.90	042.30	120.50	118.00	170.50	128.20	182.40	208.60
	012.90	58.31	000.90	67.42	001.50	074.50	118.60	136.30	119.60	144.30	121.30
Total Flight Hours (Sum)	**749.08**	**862.72**	**0053.99**	**0268.60**	**0383.88**	**0716.23**	**0902.07**	**1118.52**	**1238.40**	**1551.20**	**1637.20**
Total Flight Hours (Avg/100)	*.75*	*.86*	*0.05*	*0.27*	*0.38*	*0.72*	*0.90*	*1.12*	*1.24*	*1.55*	*1.64*
Total Failures	35.26	24.62	33.76	53.02	42.89	65.58	64.84	53.95	85.95	89.30	79.38
	56.68	48.47	40.96	40.54	64.27	54.93	55.31	64.30	89.54	86.54	85.83
	80.60	61.07	35.83	67.70	64.27	62.07	00.76	10.00	84.91	09.30	20.07
	43.89	40.65	59.97	64.91	69.88	64.37	69.06	61.35	86.03	97.24	01.55
	11.34	35.24	35.18	40.38	58.08	56.56	80.04	77.92	68.38	97.06	93.87
	41.68	63.53	84.53	75.52	80.59	95.09	85.15	97.91	01.13	04.10	11.63
	88.58	02.53	21.48	10.04	06.04	54.44	24.30	44.39	60.54	87.10	00.39
	40.07	58.39	56.34	62.58	88.86	79.45	91.98	25.41	10.16	20.30	25.86
	29.70	23.01	45.25	68.74	33.58	77.50	81.30	99.42	89.69	99.26	09.98
	46.18	53.48	58.83	55.03	63.86	79.72	12.41	16.94	08.81	14.01	06.46
Total Failures (Sum)	**273.98**	**410.99**	**472.13**	**538.46**	**572.32**	**689.71**	**765.15**	**851.59**	**885.14**	**004.21**	**035.02**
Total Failures											

(Avg/100)	.27	.41	.47	.54	.57	.69	.77	.85	.89	.00	.04
Op Avail											
	3.44	8.47	9.53	1.96	2.24	3.36	7.59	3.08	1.86	3.58	3.34
	5.86	7.21	8.86	0.95	1.73	2.47	3.20	5.89	0.40	1.48	0.97
	8.74	4.03	3.69	6.61	9.78	9.55	5.40	7.42	5.86	9.50	2.03
	6.01	4.83	1.49	2.60	2.77	7.31	6.32	3.07	1.16	9.89	0.55
	8.83	3.79	4.93	8.41	3.41	0.30	8.17	5.12	8.87	3.09	2.08
	3.28	3.29	3.40	7.49	7.19	8.35	3.51	4.02	7.10	6.52	8.00
	6.88	0.12	4.27	4.09	9.30	9.65	7.88	0.00	2.53	7.14	8.80
	8.19	6.38	2.80	7.37	2.58	2.78	4.51	1.09	0.47	0.79	4.04
	5.70	2.91	9.85	4.36	1.12	6.52	8.89	1.59	8.11	2.95	5.00
	8.82	2.54	7.84	5.31	8.23	5.30	6.90	9.63	9.48	2.10	1.07
Op Avail (Sum)	**45.75**	**53.56**	**76.65**	**99.14**	**08.35**	**35.59**	**62.37**	**70.90**	**95.83**	**17.03**	**25.88**
Op Avail (Avg/10)	*.46*	*.54*	*.77*	*.99*	*.08*	*.36*	*.62*	*.71*	*.96*	*.17*	*.26*

COMBINED MAINTENANCE & PROCESS ADJUSTMENT DATA

	.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Down Time	9.09	0.63	8.19	1.20	4.95	2.19	.40	.42	.42	.47	.89
	0.19	4.74	8.92	0.18	5.31	2.89	.47	.38	.68	.30	.05
	6.44	8.93	8.60	3.53	2.18	4.57	.32	1.46	.24	.62	.35
	0.87	0.80	1.49	6.64	3.22	0.61	0.75	.77	.76	.41	.29
	4.68	9.55	1.07	9.57	4.68	1.40	.57	.96	.16	.69	.92
	8.97	3.03	4.41	8.84	.31	0.28	.07	.84	.54	.04	.07
	4.45	7.98	7.08	1.40	2.51	3.54	5.47	.71	.34	.89	.24
	9.03	1.53	8.43	6.56	3.11	4.11	.07	.22	.84	.50	.37
	2.81	3.89	9.04	0.40	0.27	.86	.54	.62	.68	.94	.40
	4.15	2.50	9.21	8.23	5.57	5.52	.12	.56	.64	.25	.66
Down Time (Sum)	**30.68**	**13.58**	**96.44**	**86.54**	**39.10**	**22.98**	**0.78**	**6.92**	**3.30**	**4.10**	**3.25**
Down Time (Avg)	***3.07***	***1.36***	***9.64***	***8.65***	***3.91***	***2.30***	***.08***	***.69***	***.33***	***.41***	***.32***
Total Flight Hours	67.39	88.52	013.20	103.90	065.40	082.90	108.70	148.30	146.80	164.50	175.80
	82.78	49.39	004.80	72.44	042.20	068.80	088.80	120.70	155.80	155.70	182.40
	17.16	036.60	016.50	029.00	101.80	081.30	137.20	088.50	157.10	166.20	198.80
	83.42	90.15	94.92	054.50	081.30	098.10	102.20	145.40	163.90	182.20	191.10
	036.60	027.90	88.14	053.10	044.10	095.90	173.10	133.80	174.40	185.70	209.40
	56.93	090.60	075.80	158.00	172.20	130.80	202.10	182.30	224.00	218.40	223.40
	015.10	44.50	61.81	12.47	93.10	011.50	72.44	092.90	095.60	179.50	204.90
	064.10	001.70	022.90	048.20	081.50	050.90	127.10	170.80	144.40	192.90	194.50
	012.70	79.48	006.60	109.50	100.70	130.30	109.20	133.60	151.30	183.30	217.80
	012.90	74.70	005.20	103.00	018.80	032.40	114.60	134.00	140.00	165.70	185.00
Total Flight Hours (Sum)	**749.08**	**883.54**	**989.87**	**0544.11**	**0601.10**	**0782.90**	**1135.44**	**1350.30**	**1553.30**	**1794.10**	**1983.10**
Total Flight Hours (Avg/100)	***.75***	***.88***	***.99***	***0.54***	***0.60***	***0.78***	***1.14***	***1.35***	***1.55***	***1.79***	***1.98***
Total Failures	35.26	21.61	34.38	70.75	50.56	60.69	69.90	75.98	70.00	81.07	94.97
	56.68	29.91	38.59	28.83	50.44	61.61	71.91	83.69	96.64	95.71	03.80
	80.60	70.07	51.28	58.39	87.45	83.15	01.16	81.42	08.91	10.87	29.87
	43.89	41.40	39.28	55.30	73.51	78.82	79.78	87.90	00.00	18.10	18.81
	11.34	39.98	22.16	47.42	37.94	59.72	92.66	77.25	83.34	01.37	18.03
	41.68	54.93	47.86	80.72	85.06	80.11	07.48	00.04	07.06	09.55	09.09
	88.58	21.95	16.76	34.40	26.59	58.60	49.35	92.53	88.85	28.91	49.17
	40.07	54.71	61.04	74.22	95.44	82.40	06.69	15.30	14.64	32.58	24.96
	29.70	22.84	37.69	78.16	63.53	81.90	75.55	88.62	89.91	03.38	08.48

	46.18	55.13	64.41	59.02	68.98	69.50	05.24	23.17	15.17	20.51	28.17
Total Failures (Sum)	**273.98**	**412.53**	**413.45**	**587.21**	**639.50**	**716.50**	**859.72**	**925.90**	**974.52**	**102.05**	**185.35**
Total Failures (Avg/25)	*3.10*	*3.65*	*3.65*	*4.35*	*4.56*	*4.87*	*5.44*	*5.70*	*5.90*	*6.41*	*6.74*
Op Avail											
	3.44	6.74	9.45	5.18	2.78	5.43	8.49	0.61	1.08	3.07	4.44
	5.86	3.39	8.65	7.55	1.91	4.66	8.09	0.30	2.52	2.52	4.57
	8.74	6.99	8.53	7.64	4.94	1.85	7.88	5.64	1.53	3.70	6.63
	6.01	7.00	5.97	9.88	3.67	6.66	6.41	9.72	1.24	5.10	4.03
	8.83	7.73	5.84	8.06	2.98	6.00	0.23	8.64	0.82	3.56	4.59
	3.28	3.90	2.41	0.30	1.03	7.26	5.89	4.90	7.87	7.26	7.23
	6.88	0.06	0.79	5.19	4.93	3.64	1.57	8.53	9.17	3.23	6.61
	8.19	5.27	8.09	0.18	3.08	2.55	7.88	1.50	0.53	4.97	5.22
	5.70	5.44	8.59	6.67	6.69	8.54	7.73	8.53	0.26	3.35	5.48
	8.82	4.14	7.41	8.16	1.01	0.57	0.25	0.85	1.89	2.65	4.84
Op Avail (Sum)	**45.75**	**60.64**	**75.74**	**08.81**	**33.01**	**47.16**	**84.42**	**99.21**	**16.91**	**39.41**	**53.64**
Op Avail (Avg/10)	*.46*	*.61*	*.76*	*.09*	*.33*	*.47*	*.84*	*.99*	*.17*	*.39*	*.54*

PROCESS DELAY ADJUSTMENT DATA

	.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Down Time											
	9.09	2.04	7.72	0.21	9.94	1.30	7.46	8.84	1.83	2.75	6.98
	0.19	8.23	1.83	8.47	6.72	0.67	1.92	5.10	2.55	2.83	9.13
	6.44	0.06	2.06	6.14	7.98	7.50	4.56	0.08	2.63	9.99	0.48
	0.87	2.02	7.50	1.28	9.89	9.36	9.10	5.89	5.48	4.66	3.71
	4.68	5.49	4.84	8.12	9.79	1.02	1.78	3.35	2.75	2.39	4.14
	8.97	5.73	4.86	7.58	4.10	5.19	5.35	6.38	6.41	5.77	2.10
	4.45	0.74	5.65	6.12	1.92	9.18	6.97	7.69	8.71	0.93	6.49
	9.03	3.34	6.69	6.03	1.89	8.75	3.51	3.93	3.25	3.46	3.71
	2.81	2.34	8.27	2.65	1.04	6.89	2.91	6.47	8.22	5.33	3.63
	4.15	5.92	8.53	9.68	0.70	0.42	2.23	9.05	4.68	7.35	1.04
Down Time (Sum)	**30.68**	**35.91**	**37.94**	**36.27**	**23.97**	**10.26**	**25.79**	**16.78**	**16.49**	**35.46**	**31.41**
Down Time (Avg/10)	*.31*	*.36*	*.38*	*.36*	*.24*	*.10*	*.26*	*.17*	*.16*	*.35*	*.31*
Total Flight Hours											
	67.39	97.48	49.37	044.70	007.50	59.13	56.56	019.70	78.92	74.44	29.79
	82.78	29.85	74.46	98.61	49.64	13.74	89.59	67.20	65.79	50.93	003.90
	17.16	033.20	011.10	49.80	034.20	048.20	61.81	039.50	85.74	007.90	90.13
	83.42	95.40	029.00	96.66	007.50	019.40	019.50	87.55	043.70	85.49	86.44
	036.60	86.02	84.28	46.29	005.50	011.90	003.70	77.08	013.50	84.92	86.66
	56.93	034.90	068.10	043.50	075.10	065.90	040.50	048.60	041.40	068.70	122.90
	015.10	10.40	84.80	81.76	96.30	25.55	35.13	54.84	38.50	32.20	33.80
	064.10	83.89	42.71	32.54	86.98	004.80	92.82	50.32	66.03	58.16	70.19
	012.70	84.91	023.90	72.78	37.31	014.70	70.04	020.60	020.90	50.46	81.70
	012.90	43.56	52.57	94.59	86.02	005.00	87.64	001.60	37.74	12.20	00.99
Total Flight Hours (Sum)	**749.08**	**699.61**	**720.29**	**661.23**	**786.05**	**868.32**	**757.29**	**866.99**	**792.22**	**625.40**	**706.50**
Total Flight Hours (Avg/100)	*.75*	*.70*	*.72*	*.66*	*.79*	*.87*	*.76*	*.87*	*.79*	*.63*	*.71*
Total Failures											
	35.26	32.72	10.97	34.09	36.07	10.08	05.28	33.17	20.90	15.40	99.83
	56.68	12.01	34.94	40.57	25.12	14.13	35.39	33.76	27.86	29.04	48.38
	80.60	63.60	55.40	47.77	70.93	62.15	42.97	69.00	47.48	58.23	51.46
	43.89	37.83	51.83	44.19	43.39	47.13	46.04	37.16	55.75	36.80	37.61
	11.34	21.07	19.75	12.38	35.06	36.35	30.97	20.40	32.17	22.80	26.19
	41.68	40.34	55.38	46.17	59.69	55.76	35.99	46.83	34.44	52.20	81.58
	88.58	98.96	89.53	85.77	90.84	98.65	01.24	06.65	02.87	01.55	06.48
	40.07	53.94	42.58	35.62	56.98	55.04	53.30	37.64	50.49	42.82	48.37
	29.70	27.93	50.57	28.81	14.36	42.12	30.57	47.52	50.54	27.13	27.70
	46.18	36.31	46.30	64.56	63.14	65.12	57.11	62.68	47.93	37.86	26.40
Total Failures (Sum)	**273.98**	**324.71**	**357.25**	**339.93**	**395.58**	**386.53**	**338.86**	**394.81**	**370.43**	**323.83**	**354.00**
Total Failures											

(Avg/100)	.27	.32	.36	.34	.40	.39	.34	.39	.37	.32	.35
Op Avail											
	3.44	5.77	1.71	7.38	7.84	7.06	2.96	9.01	6.29	6.08	2.72
	5.86	1.34	5.99	9.12	1.35	9.30	5.98	2.55	5.12	5.27	8.04
	8.74	6.55	5.09	1.33	7.95	8.74	2.59	5.72	4.58	6.33	6.52
	6.01	6.11	9.74	5.04	7.76	8.40	8.02	2.84	9.23	4.01	4.30
	8.83	3.28	3.03	1.18	5.67	6.09	6.19	3.82	4.88	4.15	4.47
	3.28	2.12	2.59	0.27	2.80	2.50	2.61	1.16	1.58	1.89	4.17
	6.88	8.29	5.33	5.13	7.57	9.63	1.74	1.28	9.89	8.37	1.80
	8.19	3.85	0.11	0.83	4.86	8.07	4.01	2.22	3.31	3.01	2.97
	5.70	6.32	9.01	6.10	9.63	0.75	5.33	1.13	9.06	3.12	5.58
Op Avail (Sum)	8.82	1.98	9.74	6.79	5.31	5.92	4.42	6.94	2.24	0.21	7.64
	45.75	45.59	42.35	43.15	50.72	66.46	53.85	56.64	56.17	42.42	48.20
Op Avail (Avg/10)	.46	.46	.42	.43	.51	.66	.54	.57	.56	.42	.48

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APPENDIX H. RELIABILITY CALCULATIONS

INCREASE IN RELIABILITY OF TOP TWO DEGRADERS

% Increase	Nomenclature	MTBF (old)	MTBF (new)	Failure Rate	Sys Fail Rate	% Sys Fail Rate	Sys Reliability	P(fail)	MTTR	Repair Rate (p/hr)
0	Airframes and Flight Cntl Sys (1*)	6.69	6.69	0.149	0.434		0.34	0.65	0.35	6.64	0.1506
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.05			5.87	0.1704
	Utility Systems (4*)	20.41	20.41	0.049		2.306	0.11			7.04	0.1420
	Instrumentation (5*)	41.44	41.44	0.024			0.06			6.16	0.1623
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.04			3.26	0.3067
	Radio-Radar Nav/Weps (7*)	6.09	6.09	0.164			0.38			4.81	0.2079
	Ground Control Equipment	323.4	323.4	0.003			0.01			5	0.2000
	Ground Data Terminal	355.08	355.08	0.003			0.01			5	0.2000
	Explosive Devices (97)	588.17	588.17	0.002			0.00			5.31	0.1883
0.05	Airframes and Flight Cntl Sys (1*)	6.69	7.0245	0.142	0.419		0.34	0.66	0.34		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.05				
	Utility Systems (4*)	20.41	20.41	0.049		2.389	0.12				
	Instrumentation (5*)	41.44	41.44	0.024			0.06				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.04				
	Radio-Radar Nav/Weps (7*)	6.09	6.3945	0.156			0.37				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.1	Airframes and Flight Cntl Sys (1*)	6.69	7.359	0.136	0.405		0.34	0.67	0.33		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.05				
	Utility Systems (4*)	20.41	20.41	0.049		2.469	0.12				
	Instrumentation (5*)	41.44	41.44	0.024			0.06				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	6.699	0.149			0.37				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.15	Airframes and Flight Cntl Sys (1*)	6.69	7.6935	0.130	0.393		0.33	0.68	0.32		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.05				
	Utility Systems (4*)	20.41	20.41	0.049		2.547	0.12				
	Instrumentation (5*)	41.44	41.44	0.024			0.06				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	7.0035	0.143			0.36				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.2	Airframes and Flight Cntl Sys (1*)	6.69	8.028	0.125	0.381		0.33	0.68	0.32		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.05				
	Utility Systems (4*)	20.41	20.41	0.049		2.623	0.13				
	Instrumentation (5*)	41.44	41.44	0.024			0.06				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	7.308	0.137			0.36				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.25	Airframes and Flight Cntl Sys (1*)	6.69	8.3625	0.120	0.371		0.32	0.69	0.31		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.06				
	Utility Systems (4*)	20.41	20.41	0.049		2.697	0.13				
	Instrumentation (5*)	41.44	41.44	0.024			0.07				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	7.6125	0.131			0.35				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.3	Airframes and Flight Cntl Sys (1*)	6.69	8.697	0.115	0.361		0.32	0.70	0.30		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.06				
	Utility Systems (4*)	20.41	20.41	0.049		2.769	0.14				
	Instrumentation (5*)	41.44	41.44	0.024			0.07				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	7.917	0.126			0.33				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.35	Airframes and Flight Cntl Sys (1*)	6.69	9.0315	0.111	0.352		0.31	0.70	0.30		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.06				
	Utility Systems (4*)	20.41	20.41	0.049		2.839	0.14				
	Instrumentation (5*)	41.44	41.44	0.024			0.07				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	8.2215	0.122			0.34				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.4	Airframes and Flight Cntl Sys (1*)	6.69	9.366	0.107	0.344		0.31	0.71	0.29		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.06				
	Utility Systems (4*)	20.41	20.41	0.049		2.907	0.14				
	Instrumentation (5*)	41.44	41.44	0.024			0.07				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	8.526	0.117			0.34				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.45	Airframes and Flight Cntl Sys (1*)	6.69	9.7005	0.103	0.336		0.30	0.71	0.29		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.06				
	Utility Systems (4*)	20.41	20.41	0.049		2.974	0.14				
	Instrumentation (5*)	41.44	41.44	0.024			0.07				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.05				
	Radio-Radar Nav/Weps (7*)	6.09	8.8305	0.113			0.33				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.00				
0.5	Airframes and Flight Cntl Sys (1*)	6.69	10.035	0.100	0.329		0.30	0.72	0.28		
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF		0.06				
	Utility Systems (4*)	20.41	20.41	0.049		3.039	0.15				
	Instrumentation (5*)	41.44	41.44	0.024			0.07				
	Comm-Nav-IFF (6*)	53.45	53.45	0.019			0.06				
	Radio-Radar Nav/Weps (7*)	6.09	9.135	0.109			0.33				
	Ground Control Equipment	323.4	323.4	0.003			0.01				
	Ground Data Terminal	355.08	355.08	0.003			0.01				
	Explosive Devices (97)	588.17	588.17	0.002			0.01				

INCREASE IN RELIABILITY OF ALL SYSTEM COMPONENTS

% Increase	Nomenclature	MTBF (old)	MTBF (new)	Failure Rate	Sys Fail Rate	% Sys Fail Rate	Sys Reliability	P(fail)	MTTR	Repair Rate (p/hr)
0	Airframes and Flight Cntl Sys (1*)	6.69	6.69	0.149	0.434	0.34	0.65	0.35	6.64	0.1506
	Engine/APU (2*)	48.92	48.92	0.020	Sys MTBF	0.05			5.87	0.1704
	Utility Systems (4*)	20.41	20.41	0.049	2.306	0.11			7.04	0.1420
	Instrumentation (5*)	41.44	41.44	0.024		0.06			6.16	0.1623
	Comm-Nav-IFF (6*)	53.45	53.45	0.019		0.04			3.26	0.3067
	Radio-Radar Nav/Weps (7*)	6.09	6.09	0.164		0.38			4.81	0.2079
	Ground Control Equipment	323.4	323.4	0.003		0.01			5	0.2000
	Ground Data Terminal	355.08	355.08	0.003		0.01			5	0.2000
	Explosive Devices (97)	588.17	588.17	0.002		0.00			5.31	0.1883
0.05	Airframes and Flight Cntl Sys (1*)	6.69	7.0245	0.142	0.413	0.34	0.66	0.34		
	Engine/APU (2*)	48.92	51.366	0.019	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	21.4305	0.047	2.422	0.11				
	Instrumentation (5*)	41.44	43.512	0.023		0.06				
	Comm-Nav-IFF (6*)	53.45	56.1225	0.018		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	6.3945	0.156		0.38				
	Ground Control Equipment	323.4	339.57	0.003		0.01				
	Ground Data Terminal	355.08	372.834	0.003		0.01				
	Explosive Devices (97)	588.17	617.5785	0.002		0.00				
0.1	Airframes and Flight Cntl Sys (1*)	6.69	7.359	0.136	0.394	0.34	0.67	0.33		
	Engine/APU (2*)	48.92	53.812	0.019	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	22.451	0.045	2.537	0.11				
	Instrumentation (5*)	41.44	45.584	0.022		0.06				
	Comm-Nav-IFF (6*)	53.45	58.795	0.017		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	6.699	0.149		0.38				
	Ground Control Equipment	323.4	355.74	0.003		0.01				
	Ground Data Terminal	355.08	390.588	0.003		0.01				
	Explosive Devices (97)	588.17	646.987	0.002		0.00				
0.15	Airframes and Flight Cntl Sys (1*)	6.69	7.6935	0.130	0.377	0.34	0.69	0.31		
	Engine/APU (2*)	48.92	56.258	0.018	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	23.4715	0.043	2.652	0.11				
	Instrumentation (5*)	41.44	47.656	0.021		0.06				
	Comm-Nav-IFF (6*)	53.45	61.4675	0.016		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	7.0035	0.143		0.38				
	Ground Control Equipment	323.4	371.91	0.003		0.01				
	Ground Data Terminal	355.08	408.342	0.002		0.01				
	Explosive Devices (97)	588.17	676.3955	0.001		0.00				
0.2	Airframes and Flight Cntl Sys (1*)	6.69	8.028	0.125	0.361	0.34	0.70	0.30		
	Engine/APU (2*)	48.92	58.704	0.017	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	24.492	0.041	2.768	0.11				
	Instrumentation (5*)	41.44	49.728	0.020		0.06				
	Comm-Nav-IFF (6*)	53.45	64.14	0.016		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	7.308	0.137		0.38				
	Ground Control Equipment	323.4	388.08	0.003		0.01				
	Ground Data Terminal	355.08	426.096	0.002		0.01				
	Explosive Devices (97)	588.17	705.804	0.001		0.00				
0.25	Airframes and Flight Cntl Sys (1*)	6.69	8.3625	0.120	0.347	0.34	0.71	0.29		
	Engine/APU (2*)	48.92	61.15	0.016	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	25.5125	0.039	2.883	0.11				
	Instrumentation (5*)	41.44	51.8	0.019		0.06				
	Comm-Nav-IFF (6*)	53.45	66.8125	0.015		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	7.6125	0.131		0.38				
	Ground Control Equipment	323.4	404.25	0.002		0.01				
	Ground Data Terminal	355.08	443.85	0.002		0.01				
	Explosive Devices (97)	588.17	735.2125	0.001		0.00				
0.3	Airframes and Flight Cntl Sys (1*)	6.69	8.697	0.115	0.334	0.34	0.72	0.28		
	Engine/APU (2*)	48.92	63.596	0.016	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	26.533	0.038	2.998	0.11				
	Instrumentation (5*)	41.44	53.872	0.019		0.06				
	Comm-Nav-IFF (6*)	53.45	69.485	0.014		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	7.917	0.126		0.38				
	Ground Control Equipment	323.4	420.42	0.002		0.01				
	Ground Data Terminal	355.08	461.604	0.002		0.01				
	Explosive Devices (97)	588.17	764.621	0.001		0.00				
0.35	Airframes and Flight Cntl Sys (1*)	6.69	9.0315	0.111	0.321	0.33	0.73	0.27		
	Engine/APU (2*)	48.92	66.042	0.015	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	27.5535	0.036	3.114	0.11				
	Instrumentation (5*)	41.44	55.944	0.018		0.05				
	Comm-Nav-IFF (6*)	53.45	72.1575	0.014		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	8.2215	0.122		0.36				
	Ground Control Equipment	323.4	436.59	0.002		0.01				
	Ground Data Terminal	355.08	479.358	0.002		0.01				
	Explosive Devices (97)	588.17	794.0295	0.001		0.00				
0.4	Airframes and Flight Cntl Sys (1*)	6.69	9.366	0.107	0.310	0.34	0.73	0.27		
	Engine/APU (2*)	48.92	68.488	0.015	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	28.574	0.035	3.229	0.11				
	Instrumentation (5*)	41.44	58.016	0.017		0.06				
	Comm-Nav-IFF (6*)	53.45	74.83	0.013		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	8.526	0.117		0.38				
	Ground Control Equipment	323.4	452.76	0.002		0.01				
	Ground Data Terminal	355.08	497.112	0.002		0.01				
	Explosive Devices (97)	588.17	823.438	0.001		0.00				
0.45	Airframes and Flight Cntl Sys (1*)	6.69	9.7005	0.103	0.299	0.33	0.74	0.26		
	Engine/APU (2*)	48.92	70.934	0.014	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	29.5945	0.034	3.344	0.11				
	Instrumentation (5*)	41.44	60.088	0.017		0.05				
	Comm-Nav-IFF (6*)	53.45	77.5025	0.013		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	8.8305	0.113		0.37				
	Ground Control Equipment	323.4	468.93	0.002		0.01				
	Ground Data Terminal	355.08	514.866	0.002		0.01				
	Explosive Devices (97)	588.17	852.8465	0.001		0.00				
0.5	Airframes and Flight Cntl Sys (1*)	6.69	10.035	0.100	0.289	0.34	0.75	0.25		
	Engine/APU (2*)	48.92	73.38	0.014	Sys MTBF	0.05				
	Utility Systems (4*)	20.41	30.615	0.033	3.460	0.11				
	Instrumentation (5*)	41.44	62.16	0.016		0.06				
	Comm-Nav-IFF (6*)	53.45	80.175	0.012		0.04				
	Radio-Radar Nav/Weps (7*)	6.09	9.135	0.109		0.38				
	Ground Control Equipment	323.4	485.1	0.002		0.01				
	Ground Data Terminal	355.08	532.62	0.002		0.01				
	Explosive Devices (97)	588.17	882.255	0.001		0.00				

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